PRE-ENGINEERING ASSESSMENT OF AN ENERSOLVE DEMONSTRATION PROJECT

FOR

STRUCTURAL CLAY PRODUCTS AND REFRACTORIES KILN AND DRYER

KENT ENGINEERING LTD. SEPTEMBER, 1985

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FINAL REPORT

This study at the Clayburn Industries Ltd. plant at Abbotsford, B.C. was conducted under the auspices of the Canada Centre for Mineral and Energy Technology (CANMET), Energy Mines and Resources Canada, by Kent Engineering Ltd.

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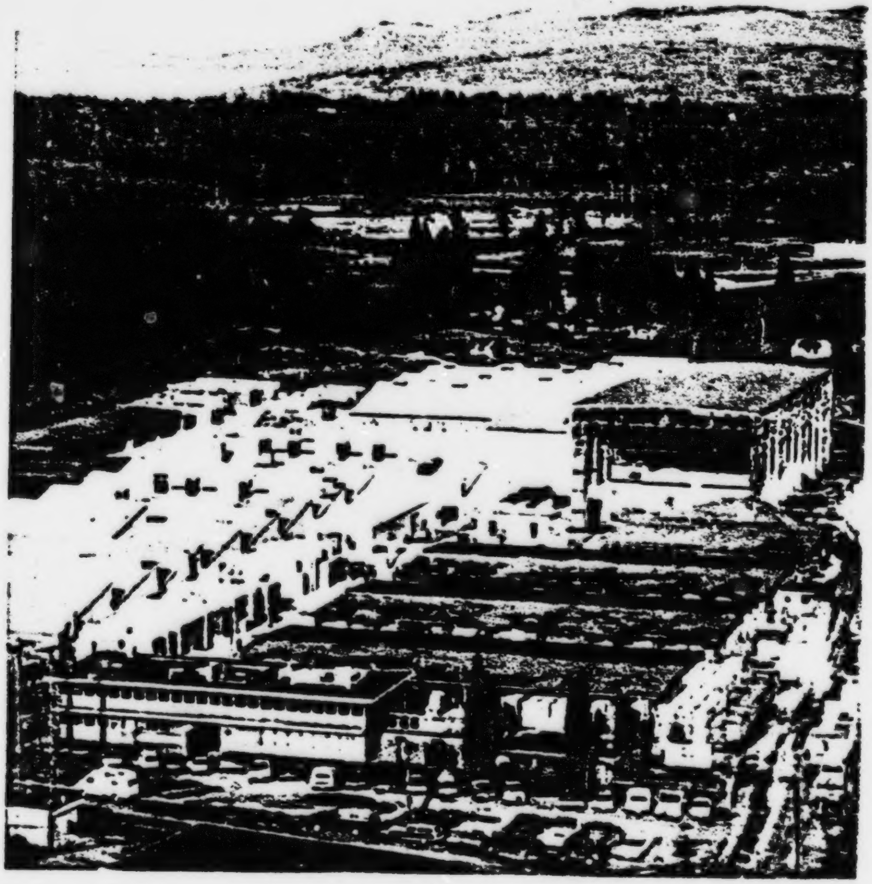

History:

The Clayburn Fireclay Company, as it was originally named, was established about 1905 and commenced operations at Clayburn, B.C., 45 miles east of Vancouver on the south side of the Fraser River. The plant was located on Matsqui Prairie adjacent to the north-westerly flank of Sumas Mountain. Shales for processing into refractories, construction brick and vitrified sewer pipe were obtained from the mountain at points 3½ miles and 4½ miles from the plant via a company owned and operated electric railway.

Better exposures and more accessible shale deposits were known to occur on the southerly flank of the mountain above Sumas Prairie and, with the construction of a railway line (The Vancouver, Victoria and Eastern Railway & Navigation Company) adjacent to the deposits, operations were commenced at Kilgard as the Kilgard Fireclay Company. The Kilgard plant, completed in 1913, soon became the centre of operations, and equipment and machinery were moved from the Clayburn site. By 1930, the Clayburn site was no longer in operation.

In 1949, a fire destroyed the Kilgard plant. Construction commenced immediately with the building of a new plant at Kilgard, specializing in vitrified sewer pipe and flue liner, and a second and larger plant was built at Abbotsford, six miles to the west specializing in refractories, and building brick.

In June 1957, the Company became associated with Harbison-Walker Refractories Limited and its name, then Clayburn Company Limited, was changed to Clayburn-Harbison Limited. Since that time the Company has changed hands several times and has been associated with Canadian Refractories Ltd. (1961) and Dresser Industries Inc. (1967) when Dresser purchased Harbison-Walker. On October 15, 1968, the Kilgard and Abbotsford operations became owned separately. Both, however, continued to manufacture clay products.

On October 31, 1974, the Company, then known as Canadian Refractories Division, Western of Dresser Industries Canada Ltd. was purchased by a group of senior employees and two new companies were formed: Clayburn Industries Ltd., representing the manufacturing facilities and sale of building brick products; and Clayburn Refractories Ltd., representing the sale and installation of refractory products. At that time the Company had manufacturing facilities in Abbotsford, B.C., refractory construction divisions in Vancouver, Calgary and Edmonton. Sales offices were in Vancouver, Calgary and Edmonton and Bellevue, Washington, in the United States.

Subsequently, U.S. sales offices for construction brick operating under Clayburn Inc. and a new refractory sales and construction division operating under Clayburn Refractories Inc. were established under one roof at Redmond, Washington. Clayburn Industries Ltd. remained the parent of all Clayburn companies.

By 1980, the Canadian company had established itself as a leader in brick and refractory technology. The company's patented Giant* brick system of hollow clay masonry was being used extensively for earthquake resistant, load bearing buildings not only in Western Canada and the U.S. but also to a lesser extent as far as Montreal, New York, Chicago, Miami, Dallas and Los Angeles. Hawaii and Alaska also made use of such Abbotsford-made brick. Refractory construction crews were completing million dollar labor and material contracts in such industries as cement and lime and petrochemical as well as smaller new construction and maintenance projects in aluminum, pulp & paper and ferrous and non-ferrous metals. Construction crews were working in B.C., Alberta, California and Brazil during the spring of 1980. Refractory products have been shipped to such distant places as Poland, Ecuador, and Indonesia.

The company has achieved international recognition for its products and services. Engineering and feasibility studies have been carried out for Mid-East brick interests. The auspicious British Ceramic Society has expressed interest in its technology. Research and development remains a significant part of this modern and progressive firm.

CLAYBURN

FOREWORD

The Department of Energy, Mines and Resources ENERSOLVE program is concerned with increasing the efficiency of utilization of oil and gas in industrial boilers, kilns, furnaces, etc. It is assumed at the outset that such process heating equipment, particularly if 10 or more years old, may not be operating, or operable, at maximum attainable efficiency of fuel use, and that some scope may exist to technically upgrade the installation to achieve greater fuel economy. The manner of obtaining more efficient fuel use may vary from the simplistic case of better temperature control instrumentation, to microprocessor control of fuel/air ratios and flow rates to follow process load. It is axiomatic that the cost of equipment retrofit should be recoverable through fuel savings over a period of time acceptable to the equipment owner.

This third set of studies is concerned with the following industries and industrial operations: billet reheating in steel manufacture, brewing and distilling, oil refining, secondary or tertiary oil recovery, primary metal extraction or refining, foundries, dairy industry and brick kilns.

PREFACE

This report provides a detailed pre-engineering evaluation of the potential for cost-effective retrofit for increasing the efficiency of natural gas utilization at the heavy clay products and refractories plant of Clayburn Industries Ltd. at Abbotsford, B.C.

This report was submitted in fulfillment of Supply and Services Canada Contract Serial Nos. 0SQ83-00237 and 0SQ4-00393, DSS File No. 03SQ-23440-4-9283-2 by Kent Engineering Ltd. under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, Canada.

The contributions, assistance and cooperation of Clayburn Industries Ltd. and their personnel, in particular Mr. Jack S. Robertson, Production Manager, for giving authorization for this study at the Abbotsford plant and Mr. Art Farr and John Lam for assistance in field tests and for supply of plant information are acknowledged with thanks. A large measure of thanks is also owed to personnel of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada, for initiating and providing guidance for this study which otherwise would not have been possible.

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TERMINOLOGY, SYMBOLS, ABBREVIATIONS AND CONVERSION FACTORS

TERMINOLOGY

1. Flue Gas Losses

$$\text{Percent Thermal Efficiency} = 100 \times \frac{\text{useful output}}{\text{gross input}}$$

$$= 100 \times \frac{\text{gross input - flue gas and radiation losses}}{\text{gross input}}$$

$$= 100\% - \%\ \text{losses}$$

Where input, output and loses are measured in the same units (eg. MJ/m^3 gas burned, MJ/h).

2. Radiation and Convection Losses

This term includes heat radiated to surroundings and heat picked up by ambient air by convection from a surface.

3. Excess Air

The quantity of air above that required for perfect combustion or in excess of the stoichiometric ratio is known as excess air and is usually expressed as a percentage of the stoichiometric quantity.

4. Schedule or Push Rate

In the operation of a tunnel kiln or dryer, "schedule" or "push rate" is the number of cars passed through the tunnel per day. Knowing the product mass per car, this can be expressed as product mass per unit time. Knowing the length of the kiln, in terms of number of cars, the residence time in the tunnel can be obtained by division.

5. Ware

A term generally used to denote a ceramic article or product.

6. Car

A car is a railway flatcar type vehicle for conveying the ware charge through dryers and kilns from the ware forming area to the ware packaging area.

7. Setting (or Pack)

The configuration in which the ware charge is set or arranged on the car to allow for air circulation through the charge and air flow through the tunnel.

8. Periodic Dryers and Kilns

These are batch chamber dryers and kilns. Shuttle dryers and kilns are periodic dryers and kilns in which the ware enters, remains and leaves on cars as opposed to others in which the ware is stacked on the floor.

9. Continuous Dryers and Kilns

Continuous dryers and kilns are usually tunnel dryers and kilns which are continuous in operation. Cars pass through them in a continuous train.

10. Firing or Burning

Includes the process of drying and heating of the ware to the silica fusion temperature or vitrification stage to convert the formed clay into a stable product.

ABBREVIATIONS AND SYMBOLS

Symbols - SI Units

N - Newton (force)
Pa - Pascal (pressure, stress)
kPa - Kilopascal (10^3 pascals)
J - Joule (work, energy, quantity of heat)
MJ - Megajoule (10^6 joules)
kJ - Kilojoule (10^3 joules)
W - Watt (power)
kg - Kilogram
kcal. - Kilogram-calories
m - Meter
mm - millimeter
g - Gram
mg - Milligram

Symbols - Imperial Units

Btu - British thermal unit
Cu.ft. or ft.^{3} - Cubic feet
cfm - Cubic feet per minute
cfh - Cubic feet per hour
gal. - Gallon
gr. - Grains
scf - Standard dry cubic foot
hp - Horsepower
psig - Pounds per square inch gauge
psia - Pounds per square inch absolute
lb. - Pound
in. - Inch
h - Enthalpy
Q - Heat content

osi - Ounces per square inch
cfd - Cubic feet per day
fps - Feet per second
mps - miles per second

Abbreviations

OD - Outside diameter
ID - Inside diameter
hr. - Hour
RH - Relative humidity
s - Second
ppm - Parts per million
yr. - Year
w.c. - Water column
H.V. - High velocity

Conversion Factors

1 kg = 2.205 lb.
1 MJ/m^3 (dry) at 101.325 k Pa and 15°C = 26.86 Btu/ft.^{3} (dry) at 14.73 psia and 59°F
1 J = 9.480×10^{-4} Btu
1 N = 0.2248 lb. force
1 MJ = 948 Btu
1 kPa = 0.1451 lb./in.^{2}
1 kJ/kg = 0.4299 Btu/lb.

Throughout the text quantities are given first in Imperial units followed by SI units in brackets. The reason for this is that the preponderance of information used for the work was in Imperial units and hence some conformity would facilitate cross-referencing with the information sources.

1.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Heat losses in structural clay products and refractories kilns and dryers, fifteen years and older, generally can be decreased by providing insulation, sealing leaks, improving combustion efficiency and improving operating and maintenance procedures. However, the reductions in fuel use thus obtained will usually be less than those resulting from an increase in production rate obtained by redesign of the existing dryer or kiln which may include the following:

- improving circulation for more efficient heat transfer from kiln gases to ware by providing recirculating fans, high velocity burners and improving configuration of the setting.
- improving combustion by replacing existing burners with high velocity burners which are capable of stable operation on a wide range of fuel-to-air ratios and of promoting mixing of kiln gases.
- better controls for control of kiln atmosphere oxygen concentrations, temperature, and draft.
- determining temperature ranges in which the ware may safely undergo faster heat-up and cooling rates and modifying the kiln accordingly for more efficient heat transfer in those temperature ranges.
- improving product recovery by better control of complete firing process, e.g., suitable temperature and humidity conditions during the different drying stages, suitable oxidation conditions during preheat, safe rates of heating and cooling, uniformity of temperature throughout the ware setting.

The study facility is a 21-year old tunnel kiln and tunnel dryer at the Clayburn Industries Ltd. plant at Abbotsford, B.C. Subjects of a less detailed study are a 7-year shuttle kiln and a 28-year old predryer. Practically all of the foregoing described means of increased fuel efficiency are applicable to the study tunnel kiln and dryer because of age, discontinued use of certain equipment components upon failure, and the present condition of the facility which is in need of extensive repair. However, the age and condition of the tunnel kiln and dryer impose practical and economic constraints on the scope of fuel saving measures that can be implemented and economically justified.

In this tunnel kiln, as in most kilns today, heat recovered as hot air from the direct cooling of ware is utilized for drying and a small quantity is allowed to enter the firing zone or furnace as secondary combustion air. Often, as in this case, if fuel is utilized to preheat the ware in kiln and to predry the ware prior to entering the dryer there is a surplus of recovered or recoverable heat from the kiln's cooling zone with respect to the dryer's heat requirement. Optimizing or conserving use of hot air then becomes economically pointless if it does not displace use of fuel, as in the predryer or the kiln itself.

Because of the inter-relation of process stages of the firing process, a change in conditions in any one part of the kiln affects all other parts of the kiln and dryer. Therefore, for fuel efficiency upgrading program for the kiln-dryer combination to be orderly and effective the program must be carried out stepwise with the results of each step evaluated before the next step is undertaken. A three-phase program is recommended which briefly is as follows:

Phase I: Process and equipment adjustments, insulation of dryer hot air supply, dryer fans and ducts and roof of kiln firing zone, connection of dryer exhaust to predryer, replacement of firing zone burners with high velocity burners, and installation of a predryer exhaust fan. Results of economic evaluations of capital expenditure items are summarized in Table IV.

Phase II: Process and problem definition study of the Phase I upgraded facility and development of criteria for further fuel use reductions through:

- increase in production rate
- further heat loss reductions
- possible heat recovery from flue gases

Phase III: Technical and economic evaluations, design and implementation of alternatives for further fuel efficiency identified in Phase II.

Phase I, the subject of this pre-engineering study, is recommended for immediate implementation. Phase II is a subsequent study and monitoring of the results of the Phase I work preparatory for the Phase III work.

Heat recovery from kiln flue gases usually is found to be unattractive for the following reasons:

- corrosivity of the flue gases.
- volume and temperature of the flue gases can be reduced by good kiln construction and operation - a temperature in the range of 300 to 340°F (149 to 171°C) is attainable.
- limited opportunities for use of the heat recovered.

Although the results of this study are not fully or directly applicable to kilns and dryers in other industries there is a high degree of commonality in areas of kiln and dryer design and operation, instrumentation and process control, and fuel use reduction opportunities with compartment and tunnel dryers in the majority of other industries, porcelain product kilns, steel forging furnaces, paint ovens, curing ovens, kilns firing bonded abrasives, reheat furnaces and periodic kilns in the heavy clay products and refractories industries.

1.0 SOMMAIRE, CONCLUSIONS ET RECOMMENDATIONS

Les pertes de chaleur dans les produits en argile de construction, fours réfractaires et séchoirs, âgés de 15 ans et plus, peuvent en général être diminués en isolant, scellant les fuites, augmentant l'efficacité de combustion et améliorant les procédures d'opération et d'entretion. Toute fois, la réduction en comsommation de combustible généralement obtenne sera moins importante que l'augmentation de production obtenue par la reconception du four ou séchoir existant, ce qui pourrai inclure:

- améliorer la circulation pour une meilleure transmission de chaleur entre les gaz du four et les produits, par l'emploi de ventilateurs de recirculation et de brûleurs à haute vitesse, et en améliorant le système d'adjustement.
- améliorer la combustion en remplaçant les brûleurs existants par des brûleurs à haute vitesse, qui peuvent opérer de manière stable sur une grande gamme de rapports air/combustible, et aident au mélange de gas du four.
- de meilleurs instruments de contrôle de concentration d'oxygène, température et tirage dans l'athmosphère du four.
- déterminer dans quelle gamme de températures les produits peuvent subir un chauffage et une cuisson plus rapide, et modifier le four en conséquence, pour une transmission de chaleur plus éfficace dans cette gamme de température.
- améliorer la récupération des produits par un meilleur contrôle des procédés de cuisson, par ex contrôle des conditions de température et d'humidité pendant les différentes phases du séchage, conditions appropriées d'oxydation pendant le pré-chauffage, taux sûr de chauffage ou refroidissement, uniformité de température pour tous les produits.

L'exploitation étudiée comprend un four et un séchoir en tunnel de 21 ans dans l'usine de Clayburn Industries Ltd., à Abbotsford, B.C. Un four à vannes de 7 ans et un preséchoir de 28 ans ont été étudiés en moins de détails. Pratiquement toutes les méthodes décrites ci-dessus pour autmenter l'efficacité du systéme sont applicable à ces fours et séchoirs, vus leur âge, la non-utilizations de pièces d'équipement hors d'état et la condition actuelle de l'exploitation qui nécessite des réparations sur une grande échelle. Mais l'âge et la condition du four et du séchoir imposent des contraintes pratiques et économiques concernant l'envergure des mesures d'économie de combustible qui peuvent économiquement.

Dans ce four en tunnel comme dans la plupart des fours actuels, la chaleur récupérée sous forme d'air chaud depuis le refroidissement direct des produits est utilisée dans la zone de combustion secondaire. Souvent, comme dans le cas présent, si du combustible est utilisé pour préchauffer les produits dans le four, ou présécher les produits avant d'entrer le séchoir, il y a un surplus de chaleur récupérée ou récuperable depuis la zone de refroidissement du four, par rapport à la demande du séchoir. Améliorer ou conserver l'utilisation de l'air chaud devient économiquement sans intérêt, si ça n'aide pas à remplacer du carburant, comme dans le preséchoir ou le four lui-même.

A cause des étroites relations existant entre les différents stages du procédé de cuisson, un changement de conditions dans n' importe quelle partie du four affecte toutes les autres parties du four ou du séchoir. De ce fait, pour qu'un programme d'amélioration de rendement du combustible du four-séchoir soit efficace, ce programme doit être exécuté pas à pas, et les résultats de chaque pas doivent être évalués avant de passer au prochain stage.

Un programme en trois phases est recommandé, comme décrit ci-dessous:

Phase I: Adjustements du procédé et de l'équipement; isolation de l'ammenée d'air chaud du séchoir, des ventilateurs et conduits du séchoir, du toit du four dans la zone de mise à feu. Connecter l'echappement du séchoir au préséchoir, remplacer les brûleurs de la zone de mise à feu par des brûleurs à haute vitesse, et installer un ventilateur d'échappement dans le présechoir. Les résultats de l'évaluation économique des dépenses capitales sout résumées dan la table IV.

Phase II: Etude de définition du procédé et des problèmes de la Phase I. Développement de critères pour une économie de combustible additionelle par:

- accroissement du taux de production
- des réductions de pertes de chaleur supplémentaires
- possibilité de récupération de chaleur depuis les fumées

La mise en place immédiate de la phase I, qui fait l'objet de cette étude d'inginierie préliminaire, est recommandée. La Phase II est une étude postérieure de préparation pour la phase III, et la revue des résultats de la phase I.

La récupération de chaleur à partie des fumées est en général considérée comme peu économique, en raison de:

- la corrosivité des gas.
- le volume et la température des gas peuvent être réduits par une bonne construction et opération du four. Une température de 300 à 340°F (149 à 171°C) est obtenable.
- utilisation limitée de la chaleur récupérée.

Bien que les résultats de cette étude ne soient pas directement et complétement applicables aux fours et séchoirs d'autres industries, la conception et l'opération des différents fours et séchoires ont beaucoup en commun: contrôle des instruments et du procédé, possibilité de réduction de combustible avec les séchoirs à compartiments ou en tunnel dans la majorité des autres industries: fours à porcelaine, fournaise de forge d'acier, fours à peinture, four à traiter, cuisson au four d'abrasifs liés, fours à recuir, et fours périodiques dans l'industri lourde des produits en argile, et des produits de l'industrie des refractaires.

2.0 INTRODUCTION

2.1 GENERAL BACKGROUND

The structural clay products branch of the ceramic industry includes the manufacture of structural clay products, comprising bricks, tile, pipe and architectural terra cotta. Refractory products usually include fire brick, insulating brick, acid resistant brick and other specialty refractory products. The manufacture of these products, when compared to the manufacture of light ceramic products such as china, pottery and the like, is generally characterized by a relatively high use of clays and fuels and large-scale plant equipment which more often is continuous and more highly automated.

Briefly, the six basic steps in the manufacture of heavy clay products are:

- mining of the clay
- clay preparation
- product shaping (soft-mud process, stiff-mud process, dry-press forming)
- drying of shaped products
- firing of dried products
- packaging of fired products

Firing at a bright red heat renders the clay article (commonly referred to as "ware") hard and durable. In the firing process, up to about 392°F (200°C) residual (mechanically bound) water not removed in the process of drying is expelled. In the range of 752° to 1472°F (400° to 800°C) the so-called "combined water" is driven off. In the temperature range of 572° to 1652°F (300° to 900°C), known as the "oxidation range", any residual carbonaceous matter is burnt away provided that free oxygen has access to the clay. The vitrification temperature range, which develops the ware's strength, starts at about 1652°F (900°C) and extends up to the highest temperature that the clay can withstand without melting which is typically 2101°F (1150°C) to 2282°F (1250°C). The process of firing, broadly defined, includes drying - the removal of mechanically bound water. The drying operation is, as a rule, carried out separately in a tunnel or compartment dryer. The balance of the process - raising the ware to maximum temperature, holding at maximum temperature (termed "soaking"), and cooling is carried out in a kiln.

2.2 DRYING, TYPES OF DRYERS AND ENERGY SOURCES

The object of drying in the ceramic industry is two-fold: (1) to confer sufficient rigidity to the ware to enable it to withstand being placed in the kiln; (2) to remove water - the presence of which in excessive amount introduces difficulties into the firing operation.

Dryers may be broadly classified as periodic and continuous dryers. Periodic or chamber dryers operate batchwise. No movement of ware occurs once it is placed in the dryer on pallets or cars, that is, into different sections of the dryer for various stages of drying. Instead, conditions for various drying stages are sequenced throughout the dryer.

Continuous dryers are tunnel dryers through which the ware is moved on cars on a fixed schedule usually countercurrent to the flow of air. Each time a car of wet ware is put into the dryer a car of dried ware emerges from the dryer at the exit end and is immediately placed in a continuous tunnel kiln - whereupon a car of fired ware also leaves the exit end of the kiln. Gases from both the dryer and kiln are usually exhausted at the charge end.

The construction of a tunnel dryer is similar to that of the latter half of the cooling zone of a tunnel kiln described later in Section 2.5.1. Cars for ware transport through the tunnel dryer and their propulsion systems are the same as those for a tunnel kiln described later in the same section.

To control a dryer it must be possible to ascertain relative humidity and temperature of the dryer atmosphere and rate of flow of gases at a number of positions in the dryer. Instruments for measurement of temperature and air flow are the same as those described for the kiln in Section 2.5.2. Relative humidity may be obtained from measurements of dry-bulb and wet-bulb temperatures. Capacitive type sensors are now also available for measuring relative humidity.

Waste heat from kilns is commonly the source of energy for dryers. It is hot air produced by the cooling of ware in the kiln after removal from the fire. Little or no attempt is presently being made to recover waste heat from the products of combustion for use in the dryer. The dampness of the combustion gases and possible presence of sulfurous gases, from fuel oil or the burning out of pyrites in the ware, makes them unsuitable for direct use in the dryer.

Some dryers in the industry use heat from primary sources instead of waste heat from kilns; others use a combination of waste heat augmented by a primary heat source such as steam or sulfur-free natural gas.

As will be explained later, the term "waste heat" is a misnomer as the heat is not really waste heat at all, but heat which can be utilized, often more effectively, in the kiln itself rather than in the dryer.

2.3 FIRING PROCESS

The object of firing a clay product is to convert a fairly loosely compacted blend of various minerals into a stable product. In achieving this conversion many chemical and physical processes come into play, the external effects of which are reflected in product quality. The chemical and physical reactions are quite complex and are not of direct interest for purposes of this work. However, an understanding of the process conditions necessary to properly fire a product is essential because energy consumption is intrinsically related to the process. For example, too long a fired preheat or firing period, or too high an oxygen concentration in the oxidation-preheat zone would consume more fuel than is necessary for firing the product.

The firing curve or process for a particular clay product is usually determined in a laboratory or pilot plant. The various tests that are performed in such laboratories are explained in a copy of Harrop's Bulletin No. 40, a copy of which is appended as Table XXC in Appendix C. This information then serves as the basis for design of a fullscale dryer and kiln. In instances where the dryer and kiln must be used for a number of products, some compromises in processes may be necessary for one or more products. This would apply especially to tunnel kilns where the process cannot be readily adjusted. The design of a tunnel kiln, therefore, is usually for one particular product on which it will work most efficiently.

The firing of raw products, referred to earlier, can be divided into three broad periods:

- removal of free and combined water
- recrystalization, and carbon, sulfur and organic binder burnout
- vitrification

Temperature ranges in which the above occur are the following:

- Up to 300°F (150°C) - mechanical water driven off
- 300 to 1200°C (150 to 650°C) - combined water driven off
- 660 to 1740°F (350 to 950°C) - oxidation of impurities in clay
- 1650°F+ (900°C+) - vitrification

During firing, kiln atmospheres influence and control important solid-gas reactions in the firing of heavy clay products. The gases of concern are CO_2, H_2O, CO, O_2, SO_2, and SO_3 - all of which are introduced into the kiln from products of combustion of fuels and by evolutions from the clay raw materials. Combustion products are the primary source of CO_2, CO, H_2O and O_2. Since air is the source of oxygen, a high volume of nitrogen passes through the kiln as inert gas. All clays give off moisture and some give off CO_2, CO, SO_2 or SO_3 due to the oxidation of carbonaceous matter and pyrite or the decomposition of carbonates and sulfates. During dehydroxylation of clay minerals about 14 lb. (6.35 kg) of water vapour, occupying 785 $ft.^3$ (22.2 m^3), is put into the kiln atmosphere for every 100 lb. (45.4 kg) of clay. It can act to reduce the oxygen content which may be undesirable for the oxidation of carbonaceous matter and pyrite to occur at a practically acceptable rate.

Oxidation-reduction reaction processes are utilized for different purposes in the firing operation. Some clay materials contain carbonaceous matter that must be burned out in an oxidizing atmosphere as the temperature of firing is raised. Oxidation proceeds as follows: Combined water is removed, the whole clay body becomes open and porous, which provides easy access for oxygen and for CO and CO_2 to escape. Conditions then are good for the oxidation process to proceed until oxide reactions start and shrinkage closes the pores. The temperature at which an oxidizing atmosphere is provided should be as high as possible to take advantage of faster reaction rates. During the oxidation period it is essential to have 100% to 150% excess air in the kiln atmosphere - but more air than this amount does not help appreciably.

The reduction of iron oxide by carbon monoxide is utilized to develop colours in structural clay products. The development and control of colour is dependent on the highest temperature the product reaches. Reduction of iron oxide at the highest temperature is often used to produce tan, brown and black products from red-firing materials. This procedure, called "flashing", is accomplished by reducing the air supply to the deficient side of perfect combustion. It is usually carried out just after firing and prior to cooling of the ware.

A typical firing curve for a structural clay product is shown in Figure 1. The various heating and cooling rate periods have been plotted proportional to time or kiln length (since the charging rate of a tunnel kiln determines dwell time). Actual times will, of course, vary from one product to another. The oxidation hold at around 1550°F (843°C) could be about 6 hours; in some cases it may require 12 to 24 hours. Not all materials need an oxygen delay, consequently this part of the firing curve may be deleted and the final temperature attained sooner. After the oxidation has been completed, the temperature should be raised as rapidly as possible. A hold of at least 2 hours should be made at or close to the maximum temperature to allow for temperatures to equalize throughout the setting and for reaction rates to slow down. Cooling should be carried out as rapidly as possible without causing damage to ware. Most clays can be cooled rapidly from maximum firing temperature to 1200°F (649°C) and again from about 600°F (316°C) to ambient temperature. However, ware usually leaves the kiln at about 245°F (118°C).

In the tunnel kiln there is a tendency for gases leaving the firing zone to rise and travel along the crown of the kiln in the preheat zone, resulting in an appreciable temperature difference between the top and bottom of the setting in the preheat zone, as illustrated in Figure 2 and Figure 3.

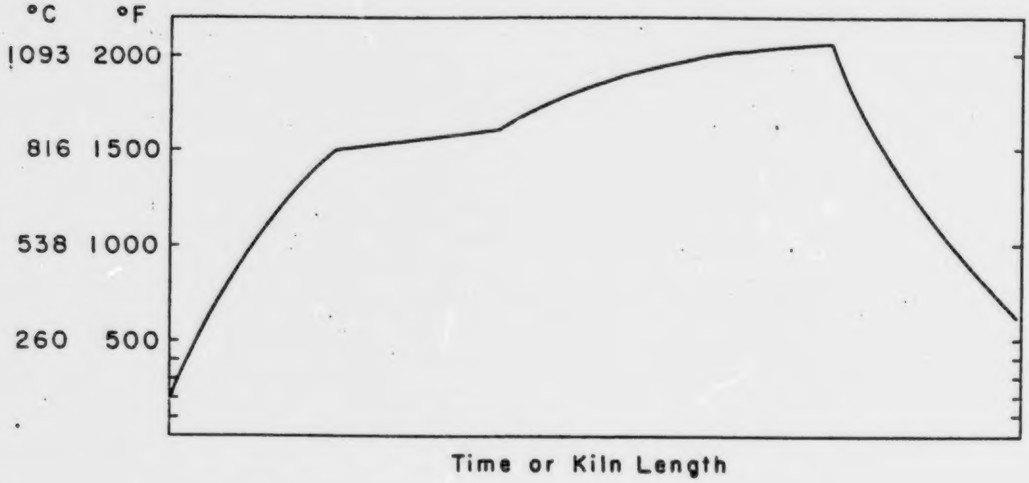


FIGURE 1 - TYPICAL FIRING CURVE
FOR STRUCTURAL CLAY PRODUCTS

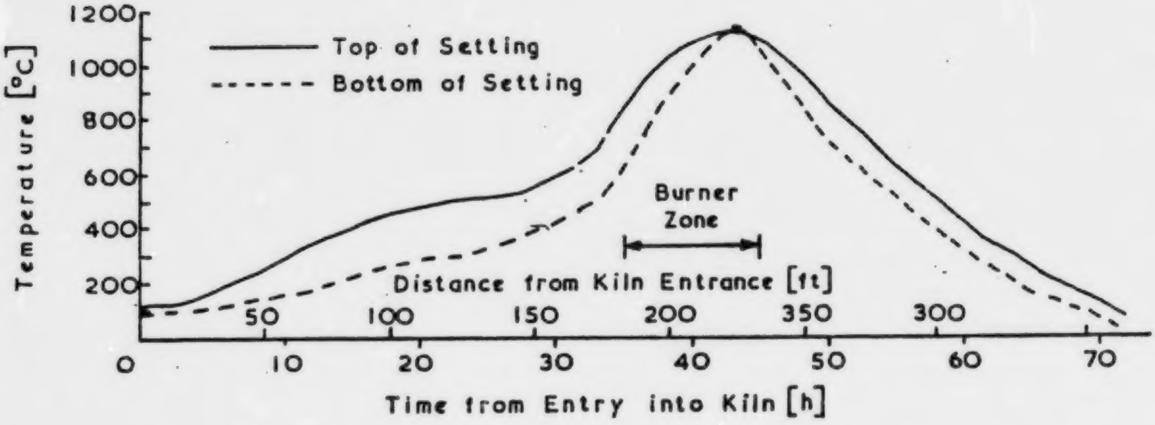


FIGURE 2 - FIRING CURVES FOR TOP
AND BOTTOM OF SETTING
(After Rowden, E. - "Firing in the
Heavy Clay and Refractories Industries"
1950 - 1964, 11, J. Br. Ceram. Soc.
(1) 72 (1966))

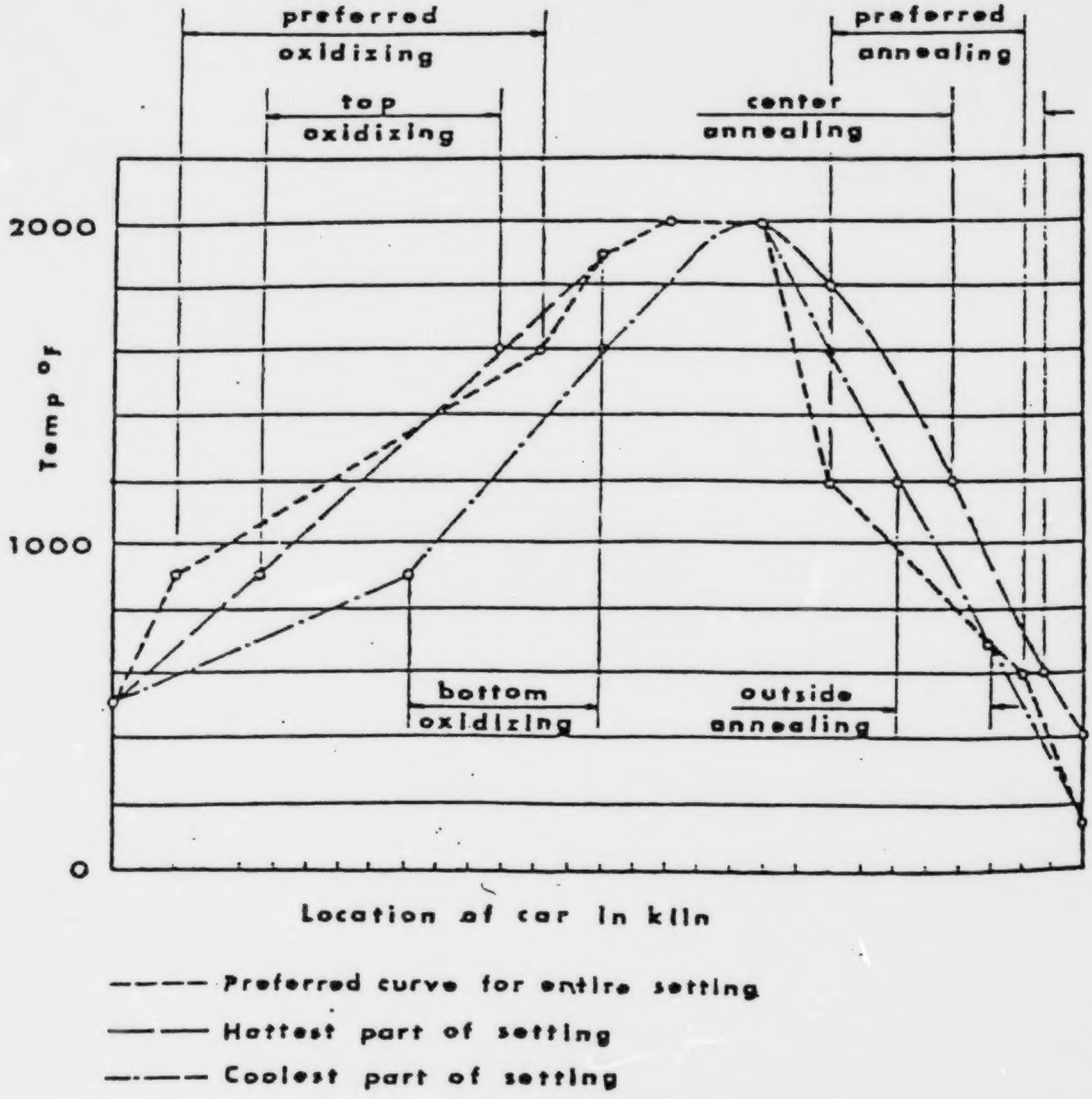


FIGURE 3 - POSSIBLE VARIATIONS
FROM PREFERRED FIRING CURVE
(After Fay, G.C., "Factors That Can Influence Fuel Consumption in Existing Kilns and Dryers", Ceramic Bulletin, Vol. 53, No. 6, 1974)

Just before entering the firing zone the temperature difference may be of the order of 540°F (300°C). The bottom temperature will then catch up rapidly as the car enters the firing zone, but this high heating rate is detrimental to ware and often results in unmarketable product. In the cooling zone, ware must be cooled slowly for annealing in the temperature range of 1200°F (649°C) to 600°F (316°C) in order to avoid damaging the ware. As shown in Figure 4, some parts of the setting on the car may come through the annealing range too quickly. Some kilns can achieve the preferred or prescribed firing curve on their crown thermocoupler, but if travelling thermocouples are set up inside the setting at different locations in the car, the temperature differentials often are found to vary substantially. Corrective action, based on travelling thermocouple data, as a rule, results in higher kiln schedules (i.e. production rate) and decreased percentage of damaged ware which bear directly on kiln performance (expressed as Btu per lb. of ware processed). A representative of one plant manufacturing face brick who was contacted in the course of this work stated that the most useful information for increasing kiln performance was obtained from a number of travelling thermocouple tracers through their kiln.

2.4 TYPES OF KILNS

Kilns may be broadly classified as periodic (or intermittent) and continuous.

The three basic types of periodic kilns are:

1. Rectangular updraft and downdraft kilns. These have openings in the floor for passage of gases, burners or firemouths in its two longer walls which support the crown, and a wicket in each of the two shorter walls for loading and unloading the kiln.

2. Round downdraft (beehive) kilns. Its operation is similar to that of the rectangular kiln. Its principal use, as in the case of the rectangular kiln, is for firing face bricks, roofing tiles, pipes, special shapes, and block and refractories.

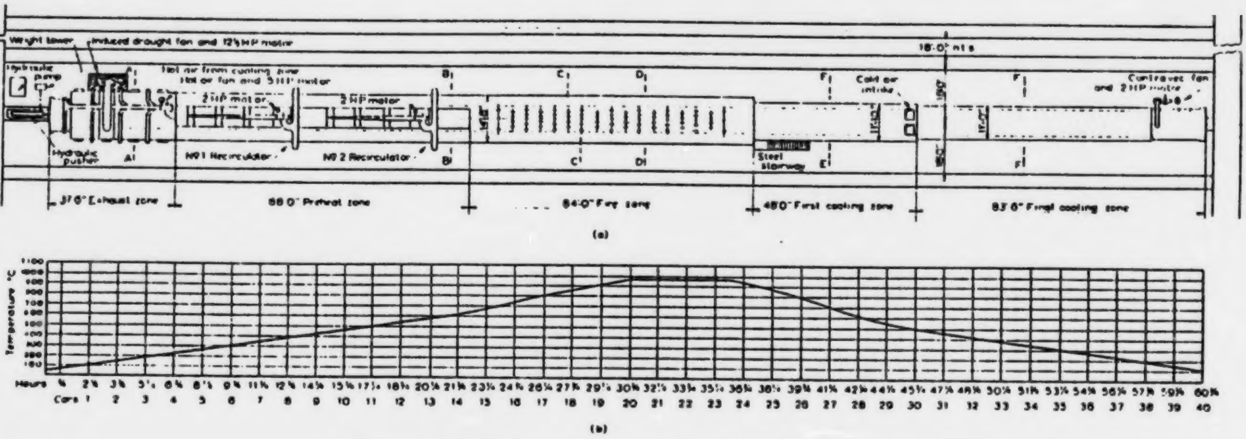
3. Shuttle kilns, which are predominantly updraft in operation, although some are downdraft. The ware is stacked on kiln cars similar to those in continuous firing.

Periodic kilns are often used for firing specialty items. Costs of firing are higher than for continuous kilns, but they provide more precise firing which usually can be afforded because of the higher price obtainable for specialty products.

Where there are a number of periodic kilns, they may be interconnected for utilization of waste heat. In such an arrangement flue gases from a kiln on full fire pass through the setting of another kiln and so preheat it before fuel is fed to its burners. In the same way kilns which have reached their top temperature are cooled down by air which is heated and passed to another kiln for drying of ware.

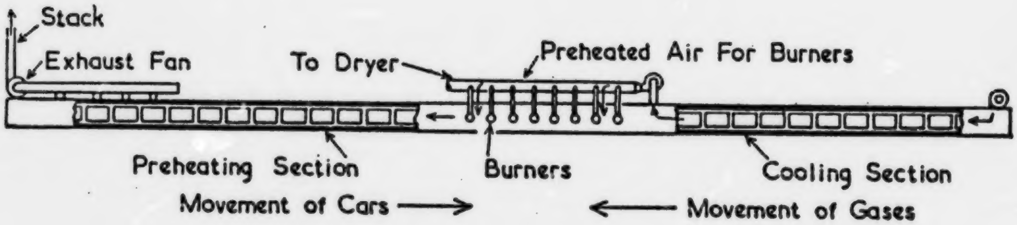
Continuous tunnel kilns are most commonly used throughout the heavy clay industry. They range in length from 300 to 650 ft. (91 to 198 m) long and each is designed to fit the demands of raw materials and economic production rates. Optimum results with tunnel kilns are obtainable when new materials and product size and shape remain constant. They are not especially suited to frequent schedule changes, but modifications may be made to accommodate different products. Such a change-over requires several hours for stabilization of new conditions during which buffer cars are often substituted for cars with product. Fuel consumed during such a change-over period is essentially wasted since it results in no useful product.

Illustrations of tunnel kilns obtained from various literature sources are shown in Figure 4.



Modern (1953) *Gibbons top-fired tunnel kiln using fuel-oil* (*Gibbons*, G39):

(*a*) *plan*
(*b*) *approximate heat curve*



Section of direct-fired tunnel kiln (after Norton)

FIGURE 4 - ILLUSTRATIONS OF TUNNEL KILNS

2.5 TUNNEL KILNS

2.5.1 Historical Development

The tunnel kiln as built some 30 years ago was the so-called "through-draft-kiln" with a preheat zone, a firing zone, and a cooling zone in order of ware travel. Air entered the ware exit at the end of the cooling zone and flowed countercurrent to movement of ware. Thus, the kiln comprised essentially a firing zone with a countercurrent flow heat recovery section at each end. Air/ware (A/W) ratios were approximately as follows:

Entering firing zone : 0.9
Infiltrated into firing zone : 0.3
Leaving firing zone : 1.2 (i.e. 0.9 + 0.3)

The weights of air and ware are nearly the same because the specific heats of both air and ware are very nearly the same. The through-draft-kiln, from a heat economy viewpoint, was an ideal system comprising a firing zone or furnace with countercurrent heat exchangers at each end. Cooling air in cooling the ware became heated and in passing through the firing zone was partly used as combustion air; gases leaving the firing zone preheated the ware as it travelled to the firing zone. Heat losses from the kiln were due to:

Flue gas extraction
Heat conductivity through walls and crowns
Discharge from the kiln of not fully cooled ware and kiln cars

During the building boom following the Second World War need arose to increase production of through-draft-kilns. Since most kilns could not be lengthened, this was done by installing burners in the preheat zone thus allowing more rapid heat-up of ware prior to firing. Recirculation of air in a kiln section upstream (relative to ware flow) of the burner section would replace in effect the heat recovery kiln section given up to preheat burners. The air requirement of the preheat zone for heat transfer by convection was now largely met by the supply of air at the burners and the previous quantity of air from the cooling zone was no longer required. As a result, hot air from cooling of ware had to be extracted from the kiln just after the firing zone. The obvious use of the hot air so extracted, which came to be viewed as "waste heat", was for drying of ware, a practice which has been carried through to present-day tunnel kilns. Since it was often impossible to physically lengthen the cooling zone, the cooling zone was effectively made longer by adoption of air recirculation techniques for rapid cooling of ware in temperature ranges given earlier, where damage to ware would not occur.

2.5.2 Construction of Tunnel Kilns

The construction of a tunnel kiln can be viewed as comprising three zones. Variations from kiln to kiln are in the number and type of sections or subdivisions of the zones. For example, a preheat zone may comprise a flue section, a recirculating section and a preheat burner section. A subdivision of a tunnel kiln is illustrated in Figure 5.

1. Preheat Zone

   In this zone the ware is brought from room or dryer-exit temperature to the temperature at which it can safely enter the firing temperature in the firing zone. The preheat zone is constructed of common bricks near the entrance, low temperature insulating blocks along most of its length and more refractory insulating blocks or firebrick backed with low temperature insulation as the firing zone is approached.

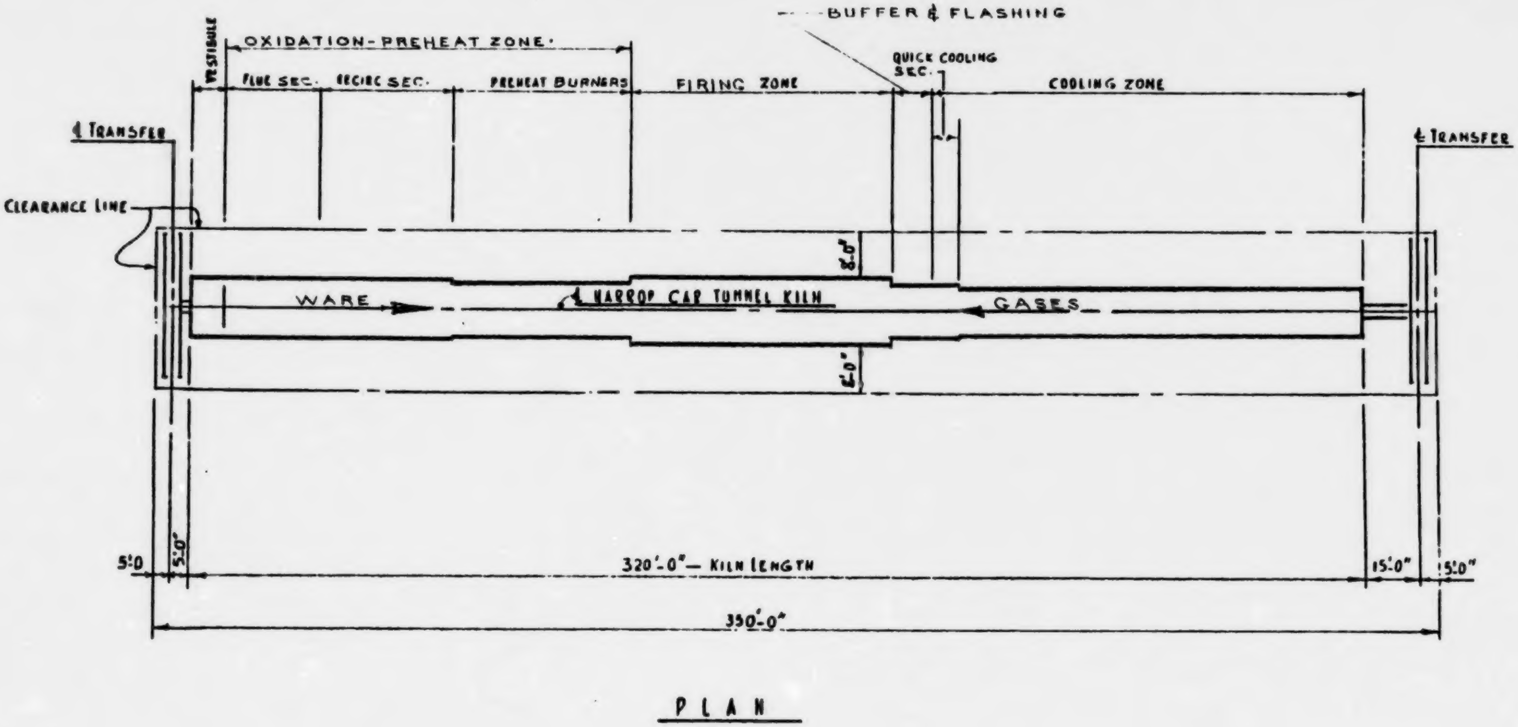


FIGURE 5 - ZONES AND SECTIONS OF TUNNEL KILN
(Clayburn Industries Limited, No. 2 Kiln)

2. Firing Zone

In the firing zone the already hot ware is gradually raised to and held at its final temperature. Heat is supplied by the burning of fuel. Materials and methods of construction of the firing zone are of extreme importance as there can be no routine maintenance of the inside of the tunnel. The inner face of the firing zone is built of the best refractory for the temperature to be used. The refractory is backed by insulating blocks and then further by low temperature insulating blocks or loose filling such as diatomaceous earth. Alternatively, the new refractory insulating blocks can be used directly as the kiln lining. More recently, the interior of firing zones of some kilns is being lined with ceramic fiber boards or blankets to reduce heat losses.

3. Cooling Zone

The cooling zone of the tunnel kiln generally plays the dual role of cooling the fired ware and producing hot air for use in a dryer or preheater. [A preheater is a short tunnel located between the dryer tunnel and the kiln for preheating ware. Ware should enter the kiln above 212°F (100°C) in order to avoid condensation of flue gas moisture. Preheating in a preheater would be necessary if the ware left the dryer at less than 212°F (100°C) or if it was allowed to cool in ambient air prior to entering the kiln.] The flow of cooling air must be regulated to give the prescribed cooling rate. In closed-end kilns the air supply can be regulated; in open-ended ones the draft has to be regulated at offtakes and flues. The heated air may pass directly into the firing zone as combustion air or it may be extracted for other uses such as drying. In most kilns only a small fraction enters the firing zone with the major portion extracted for drying.

4. Ware Transport Through Kiln

The normal method is to transport the ware through the kiln on cars travelling on rails. On the car deck is constructed an overlay of insulating and refractory slabs sufficiently thick to protect the car steelwork from the heat of the kiln. At the sides of the cars metal flanges dip into troughs of sand running down each side of the kiln to prevent air infiltration and the escape of kiln gases into the under-car compartment, or, as in the case of hot zones where kilns do not have sealed under-car compartments, into the ambient air. The effectiveness of the sand seal is augmented by tongue and groove construction of the refractory slab and corresponding ledge projections from the kiln walls. The ends of cars are also sealed on contact by means of a strip of resilient material such as ceramic fiber. Air is usually blown onto the wheel track in the hot zones to obtain sufficient cooling of the cars.

5. Propulsion of Cars Through Kiln

The movement of cars through the kiln, in most cases, is continuous with the means of propulsion applied to the end car only. The propulsion unit consists of a cylindrical ram to which oil is pumped. The amount of oil passing from the pump to the ram can be finely adjusted to control the speed at which the ram moves forward.

6. Tunnel End Closures

Some kilns have air locks at both ends so that flow conditions in the kiln will not be disturbed by the entrance and exit of cars. The majority of tunnel kilns have an air lock only at the charge end with or without a door at the exit end. The air lock is in the form of a vestibule for holding one car at the end of the tunnel which remains isolated from the tunnel by means of a sliding door while the charge door is open.

7. Burners

The importance of atmosphere control in the firing of kilns has already been emphasized. Burners in the oxidizing preheat zone must be capable of providing excess air for carbon and pyrite burnout. Burners in the firing zone should operate near stoichiometric fuel/air ratio when using 100 percent primary air and in some instances fuel rich when preheated combustion air is available from the cooling zone. A typical kiln built in the 1950s or 1960s might have sealed-in nozzle mix excess air burners in the oxidation-preheat zone (such as North American Series 223G XSA gas burners) which may be operated with up to 400 percent excess air and up to 50 percent excess fuel. The firing zone might have open dual-fuel nozzle mix burners (such as North American Series 225) which are suited for furnaces having a combustion temperature of 1600°F (871°C) or higher.

Heat transfer in the preheat and cooling zones of the kiln is primarily by convection which depends on the temperature differential between the ware and the gases and the amount of gases passing over and around the ware. Circulation of kiln gases through the setting then is of major importance in obtaining satisfactory heat transfer. Since they became available in 1970, high velocity burners have been the primary tool for accomplishing air recirculation within the kiln. Initially they were installed in the preheat zones of kilns; more recently they are being installed in firing zones as well. Also, recirculating fans are continuing to be used for increasing heat transfer rate, but maintenance tends to be high on fans operating at high temperatures.

High velocity burners have the following characteristics and advantages:

a) High flame tile outlet velocity - typical 350 fps. (107 mps).

b) High penetration and thrust-causing recirculation of gases surrounding the flame and more even heat distribution through out the kiln. This induced recirculation makes excess air unnecessary to keep flame temperatures at the desired level.

c) High velocity burners need direct electric ignition; they will not light from a hot furnace.

d) Stable operation from 2000 percent excess air to 30 percent excess fuel.

e) The high velocity burner's effectiveness is reduced at low inputs. Where a number of burners are used they are best pulse-fired, i.e. burners are either at high fire (on stoichiometric ratio) or they are off. A set temperature is maintained not by regulating fuel input to all burners but by keeping on the required number on high fire.

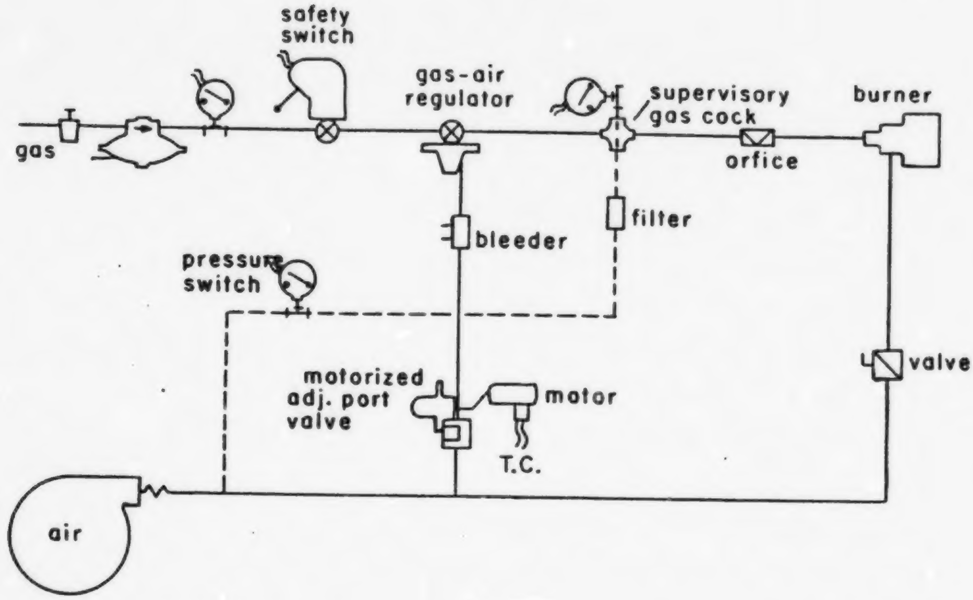
8. Burner Systems

Commonly used burner systems for the preheat zone and the firing zone are illustrated in Figure 6. The preheat zone burner system provides a constant air supply to the burners (at 16 to 24 osi) and the amount of gas fed to the burners may or may not be regulated by a temperature controller. This system provides a variable amount of excess air by controlling or setting gas flow in accordance with the flame temperature that is required. At the same time the flow of air must be sufficient to maintain an oxidizing atmosphere in the preheat zone at all times.

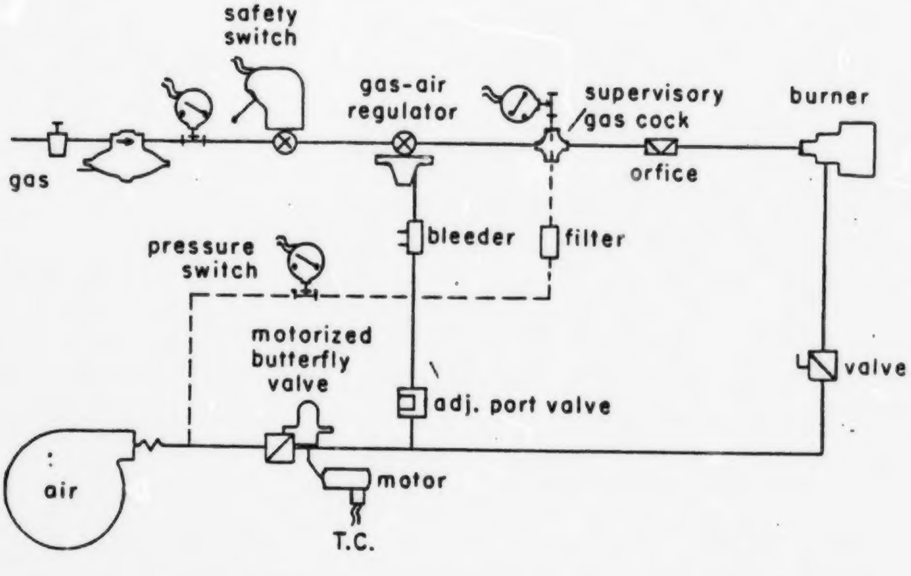
The firing zone burner system maintains a constant gas/air ratio. Here the air to the burners is controlled and the flow of gas is controlled by a cross-connected gas/air ratio regulator. The proper gas/ratio is obtained by adjusting limiting orifice valves and for greater accuracy measuring the gas flow with a metering orifice as well.

9. Instrumentation

Instruments most commonly use in monitoring and controlling kilns are those for measuring temperature, for indicating gas flow and for analysing gases.



Excess air burner system with constant air supply to burners



Excess air burner system with constant gas-air ratio at burners

FIGURE 6 - TYPICAL BURNER SYSTEMS

Kiln atmosphere temperatures throughout the kiln, of flue gases and of extracted hot air are as a rule measured by thermocouples. All temperatures are usually read hourly from a remote indicator in the control room and recorded in the operator's log. Temperatures in the firing zone usually are under automatic control by temperature controllers and recorders.

The most common instrument for measuring gas flows in ducts and stacks to and from tunnel dryers and kilns is the Pitot Tube. Anemometers and velometers may also be used.

The Orsat Apparatus is generally used for measuring flue gas and kiln atmosphere compositions providing determinations of volume percentages of CO_2, O_2 and CO. The more modern analyzers employing in-situ zirconum oxide probes and other sensors may be used to provide continuous indication and control of gas compositions in the kiln.

Gauges for measurement of draft are essential for kiln draft control the most common being the inclined draft gauge. Automatic draft control is essential. This is usually accomplished by holding a prescribed draft condition in a certain part of the kiln by means of a pressure controller which modulates a damper on the exhaust fan. Alternatively, the fan may be equipped with a variable speed motor with the advantage of savings in electric power.

2.5.3 Operational Aspects of Tunnel Kilns

1. Fuels

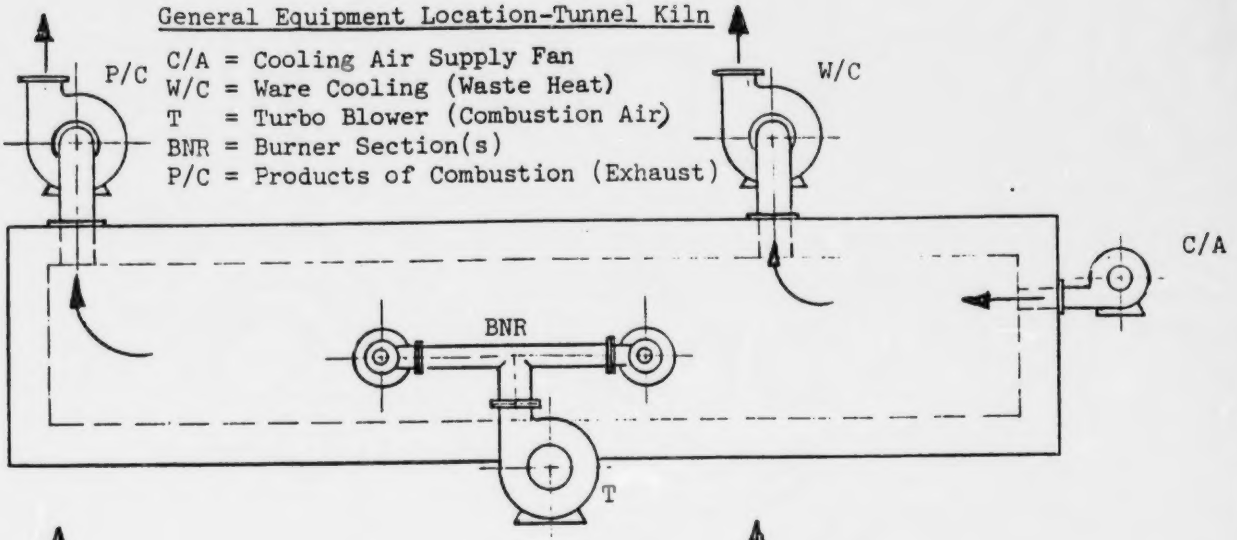
Tunnel kilns for heavy clay products may be fired with coal, oil, producer gas or natural gas. Three southern U.S. brick manufacturers reportedly were installing wood, coal and lignite gasification systems in 1983. One equipment manufacturer (M.E.C. Co.) markets a system for firing a kiln directly with hogged fuel. In June 1980 a 24-brick wide kiln in Augusta, Georgia, was reported as fired with sawdust mixed with clay and introduced through 21 burner groups from the top of the kiln. The sawdust in the clay burns out during firing, producing a lighter brick with improved insulating properties.

2. Kiln Draft

Simplified illustrations of gas travel and draft in tunnel kilns appear in Figure 7.

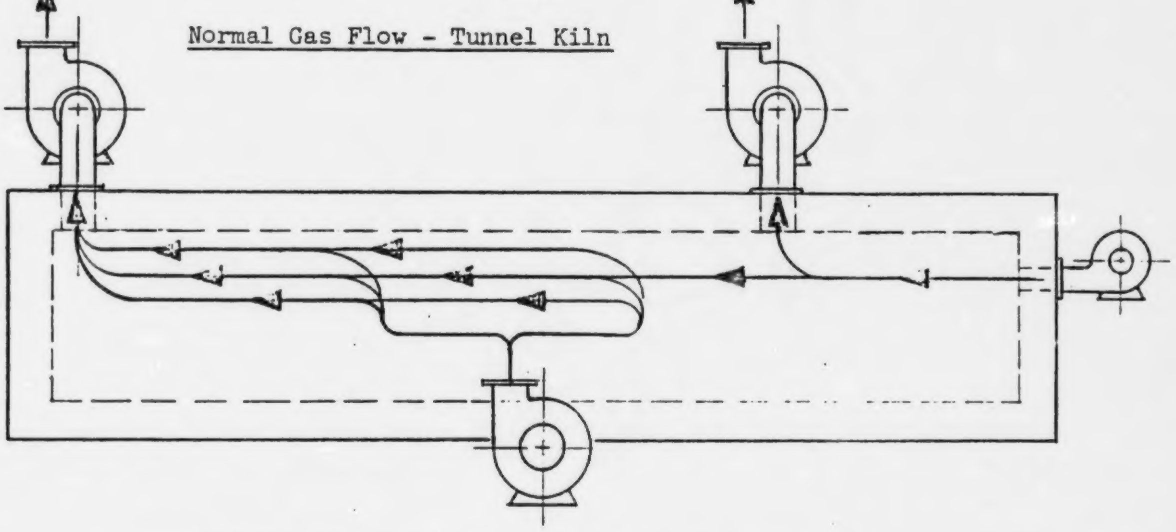
In a tunnel kiln fresh air is brought into the cooling zone to cool the ware and to provide hot air for drying. It is desirable, for reasons of effective utilization of kiln space or length, to draw off the heated air as close as possible to the firing zone exit. At the same time, the main exhaust fan is pulling the firing zone furnace gases up the tunnel in the same direction to preheat the incoming ware and to be exhausted to the atmosphere at the charge end of the tunnel. If no cooling air is to enter the firing zone and no products of combustion are to be withdrawn with the hot air to the dryer, then a zone of stagnation must exist between the firing zone exit and the hot air take-off. In practice it is difficult to balance kiln pressures to obtain such a stagnation zone. Since products of combustion in the dryer air supply may be detrimental to ware it is a safer alternative to allow some hot air from the cooling zone to pass into the firing zone. However, in most cases, often because of a high demand for hot air for drying, and where natural gas is used for firing - the products of combustion up to a certain proportion of total gases in hot air usually are innocuous to drying. When a kiln is thus back-drafting it is usually doing so only on top along the crown while preheated air from cooling enters the firing zone on the bottom.

General Equipment Location-Tunnel Kiln



C/A = Cooling Air Supply Fan
W/C = Ware Cooling (Waste Heat)
T = Turbo Blower (Combustion Air)
BNR = Burner Section(s)
P/C = Products of Combustion (Exhaust)

Normal Gas Flow - Tunnel Kiln



Typical Pressure Profile - Balanced Tunnel Kiln

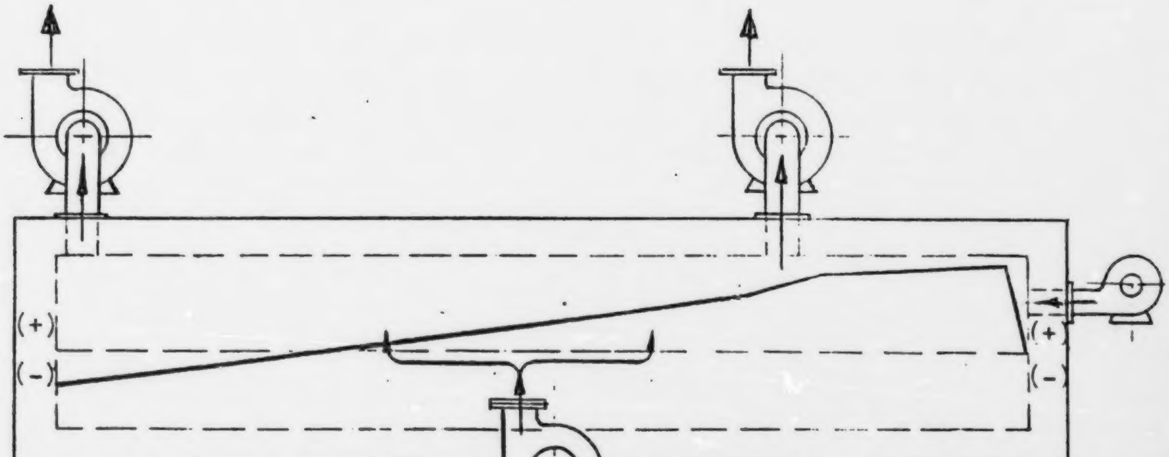


FIGURE 7 - SIMPLIFIED ILLUSTRATIONS OF GAS TRAVEL AND DRAFT IN TUNNEL KILNS

Ideally, if heavy clay ware could be cooled with relatively little air, it would attain a high temperature and it could then be passed into the firing zone as preheated combustion air. High-speed gas with little primary air could then be injected into it whereupon combustion would occur without a localized flame. Efficient heat exchange from cooling heavy clay ware to give a small quantity of hot air is difficult to achieve (however, it can be done with thin ware). Cooling of heavy clay ware usually produces a large amount of moderately hot air, the volume of which is too great to allow it all to enter the firing zone as it would dilute the heating effect of burning gas. A substantial part must therefore be removed and used elsewhere, such as in a dryer or preheater.

Draft in the tunnel kiln is controlled by maintaining a neutral point or zero draft at some point in the tunnel by controlling the output of the exhaust fan. Such a neutral point is usually selected near the entrance to the firing zone. The preheat zone of the kiln is usually under negative pressure - it being highest at the charge end where it may be in the range of 0.25 to 1" w.c. The highest potential for air infiltration then exists in the preheat zone. The setting of the charge itself should be so proportioned that a high gas velocity is maintained throughout the length of the preheat zone without causing an excessive pressure drop and high power consumption by the exhaust fan. Velocities in the preheat zone generally are in the range of 500 to 2000 fpm (152 to 610 m/min.).

2.5.4 Continuous Dryer and Continuous Kiln Efficiencies Defined

Overall Thermal Efficiency (N) of direct continuous dryers in which air is not reheated between inlet and outlet is given by the following expression:

$$N = \frac{100\ Qd}{Qs} = \frac{100\ (T1-T2)}{T1-Ta}$$

Where,

Qd = heat actually used for drying, Btu/hr.

Qs = heat supplied to the dryer, Btu/hr.

T1 = inlet gas temperature, °F

T2 = exit temperature for an equivalent adiabatic dryer, °F

Ta = inlet temperature to air heaters, °F

The efficiency equations indicate the following:

(1) Increasing T1 with T2 constant increases efficiency and reduces air requirements.

(2) Increasing Ta by recirculation of exhaust gases, for example, increases efficiency. The increased efficiency must be balanced against the larger dryer size required.

1. Ceramic Dryer Thermal Efficiency

In the ceramics industry the thermal efficiency of a dryer is more simply expressed as:

$$N = \frac{\text{Heat used in evaporating water (i.e. latent heat) X 100}}{\text{Total heat input}}$$

2. Kiln Performance and Thermal Efficiency

In judging the performance of a kiln, it is necessary to take a number of factors into account namely,

a) Amount of fuel consumed and its calorific value (which is of first importance along with b).
b) Quantity and quality of ware produced.
c) Proportion of ware that is wasted or requires refiring.
d) The temperature needed to fire the ware.
e) The amount of carbonaceous matter in the clay.

It is not possible to describe kiln performance adequately in a single expression. The expression,

$$\frac{\text{Energy input (e.g. in Btu)}}{\text{Weight of saleable goods (e.g. in lb.)}}$$

sometimes referred to as the specific heat consumption, perhaps includes as many of the important factors as is possible. Therefore, numbers such as Btu/lb., often used in trade journals, usually are not in themselves a totally valid basis for comparing performances of different plants.

The thermal efficiency of a kiln concerns the effective use of the potential heat supplied to the kiln both in the ware and in the fuel and the extent of heat losses from the kiln structure with the flue gases, and with the fired ware. Although these are prime considerations, in practice they also have to be related to the ouput of saleable ware.

The best theoretical basis for deriving the thermal efficiency of continuous kilns is probably obtained by considering in relation to total heat input only that amount of heat which must be given to the green ware and which is not recoverable afterwards. This comprises the latent heat at 59°F (15°C) of the mechanical and combined water in the ware and the heat required to complete other irreversible reactions in the clay such as decomposition of carbonates. Any hot air used for extraneous purposes must also be taken into account.

Harrop Industries Inc., suppliers of tunnel kilns and services to the ceramics industry, use a thermal efficiency incorporating the above considerations, which is defined as,

$$\frac{\text{Theoretical Btu/lb.} \times 100}{\text{Actual Btu/lb.}}$$

where the "Theoretical Btu/lb." is their own developed figure which depends on the firing temperature and specific heat of the material. In terms of Harrop's efficiency the efficiency of older kilns is in the range of 40 to 60 percent. They feel that the efficiency of such kilns, through modifications in operation and design, can be increased up to 75 percent. In new kilns, they feel 80 percent efficiency is possible.

2.5.5 Methods Generally Used or Proposed for Reducing Fuel Consumption in Existing Kilns and Dryers

Reducing fuel consumption in an existing facility involves one or more of the following:

a) Improving combustion efficiency.
b) Increasing heat transfer rates.
c) Reducing stack and radiation losses.
d) Modification of the kiln or dryer for increased production. With increased production an incidental gain in fuel efficiency follows since stack and radiation losses and fuel input do not increase in the same proportion as production.

1. Dryers

The performance of dryers can often be improved through a sound analysis of the dryer's existing performance and a determination if the existing dryer meets design conditions of new dryer design for the existing application. Changes can then be made as found necessary in fans, ducts and heating systems to improve conditions in the dryer. Such changes usually involve improving recirculation and controls and adjusting the throughput of air.

Heat losses can be reduced by insulation of walls and crowns, ducts and fans.

2. Tunnel Kilns

Some of the methods generally used or proposed for reducing fuel consumption of kilns are the following:

a. Seal walls and crowns of tunnel, especially in negative pressure portions such as the preheat zone, and improve car seals to minimize air infiltration.

b. Install more efficient burner systems such as high or medium velocity burners. Modify kiln setting if necessary to suit the new burner.

c. Improve cooling by means such as quick cooling immediately after the firing zone, providing at least two hot air take-offs beyond the quick cooling section for better control of cooling rate, and a quick cooling section at the end of the cooling zone.

d. Improve insulation in the preheat and firing zones by means such as:
   (1) Ceramic fiber blanket inside the tunnel.
   (2) Back-up insulating brick with ceramic fiber blanket or a thick layer of diatomaceous earth.
   (3) Insulate exterior walls with fiberglass or rockwool.

e. Improve insulation of cartops and improve and maintain car seals.

f. Operate the kiln at peak capacity.

g. Monitor exhaust temperature and use travelling thermocouples to determine if setting have been penetrated well enough to allow a faster firing schedule.

h. Use an oxygen analyzer to monitor and minimize excess air.

i. As a minimum, automate draft and temperature controls.

j. Operate with minimum number of burners as possible such that each burner operates at near-maximum input.

k. Use preheated combustion air to burners.

l. Install under-car cooling and heat recovery system.

m. Install exhaust heat recovery if recovered heat can be effectively utilized.

2.6 OBJECTIVES OF STUDY

The objectives of this study and report (Phase I) are to provide a pre-engineering evaluation of the potential for cost-effective retrofit for increased fossil fuel utilization efficiency at the Clayburn Industries Ltd. plant at Abbotsford, B.C., namely:

1. To identify site-specific oil or gas burning industrial units and systems which show potential for energy conservation by effecting improvements in operational efficiency and which are available for testing and upgrading.

2. To conduct site investigations and tests to establish data on fuel use, combustion and system efficiencies, process load characteristics with time, etc.

3. To conceptualise equipment upgrading and retrofit procedures to improve efficiencies, and estimate cost/benefit impact.

4. To estimate the project costs of subsequently implementing modifications and monitoring performance, namely the following:

Phase II	Detailed engineering and estimation of costs for modification and retrofits identified in this pre-engineering study referred to as Phase I.
Phase III	Installation of retrofit equipment and commisssioning and acceptance by the owner of upgraded units or systems.
Phase IV	A nine-month monitoring and maintenance program of the upgraded facilities.

3.0 DESCRIPTION OF STUDY DRYER AND KILN

The study tunnel dryer and tunnel kiln are located at the plant of Clayburn Industries Ltd., Abbotsford, B.C. A cursory study was also made of other fuel consuming plant components, namely predryer for stiff-mud process products and a shuttle kiln and dryer. The shuttle kiln is, to a large degree, proprietory equipment and any modification would have to be done in consultation with its manufacturer. In view of this, the manufacturer was requested what, in his opinion, the scope for improvement in performance was. The predryer had its genus from an in-plant design in 1957 and has undergone numerous modifications since then, such that at present, its workings and performance, and raison d'etre, remain clothed in an aura of mystery. Hence, a comprehensive study of it would be a project in itself. The plant has another tunnel kiln-dryer combination, supplied by Allied Engineering Division of Ferro Corp. in 1959, which was shut down a few years ago and it has not operated since. It remains doubtful if it will be operated again.

A simplified plant layout and process flow diagram are shown in Figure 8.

The study kiln and dryer were supplied by Harrop Industries Inc. in 1964. A description of the kiln and dryer is provided in a copy of the Harrop proposed general specification in Appendix A. Some photographs of the kiln and dryer are found in Appendix B. Zones and sections of the kiln are illustrated diagramatically in Figure 5. A plot plan of the kiln and dryer is found in Figure 9. Harrop engineering drawings for the kiln and dryer are included in Appendix F.

Drawings for the stiff-mud predryer are included in Appendix G. Bickley specifications and drawings for the shuttle kiln and dryer are found in Appendix H.

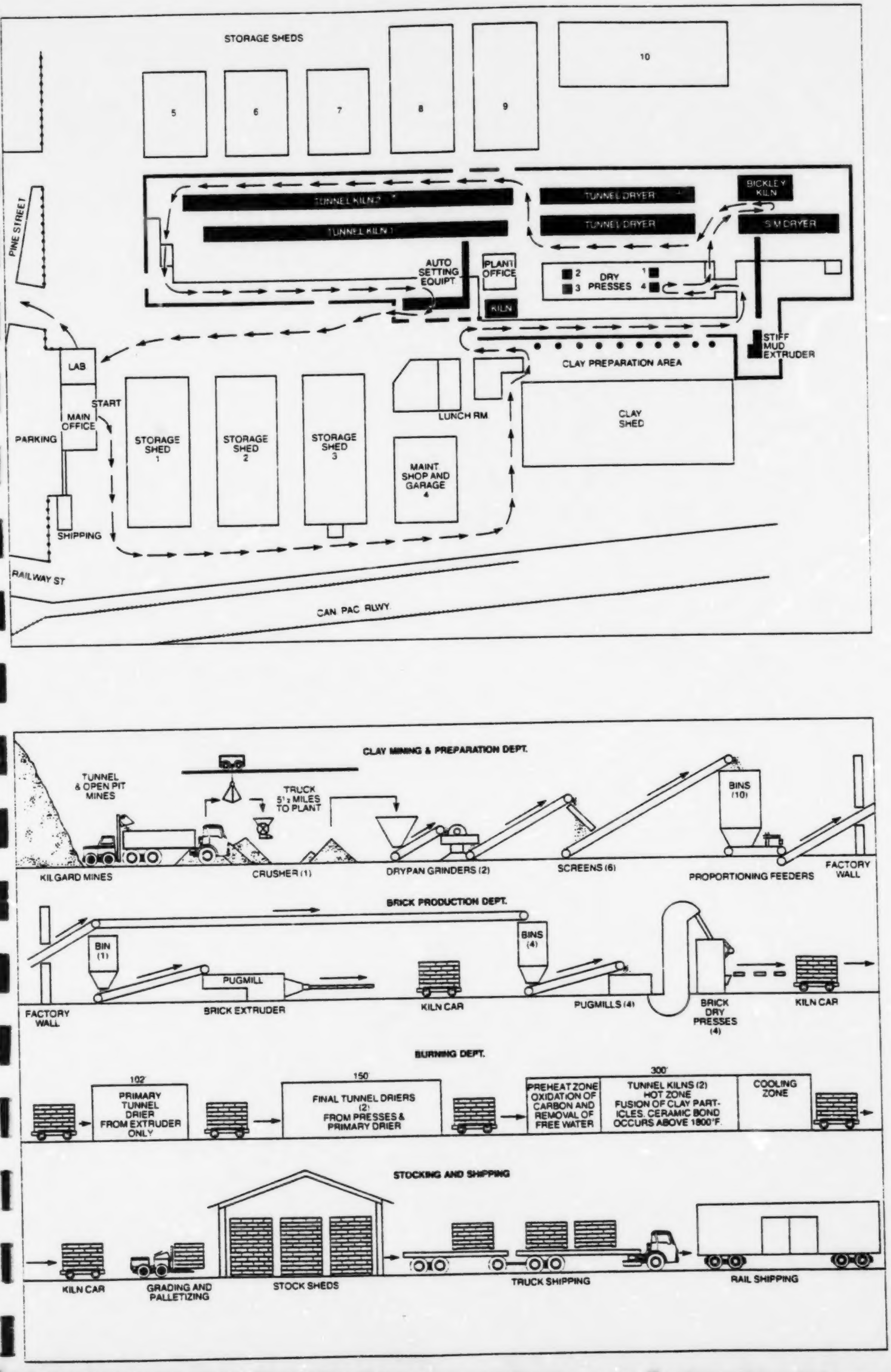


FIGURE 8 - SIMPLIFIED PLANT LAYOUT & PROCESS FLOW DIAGRAM

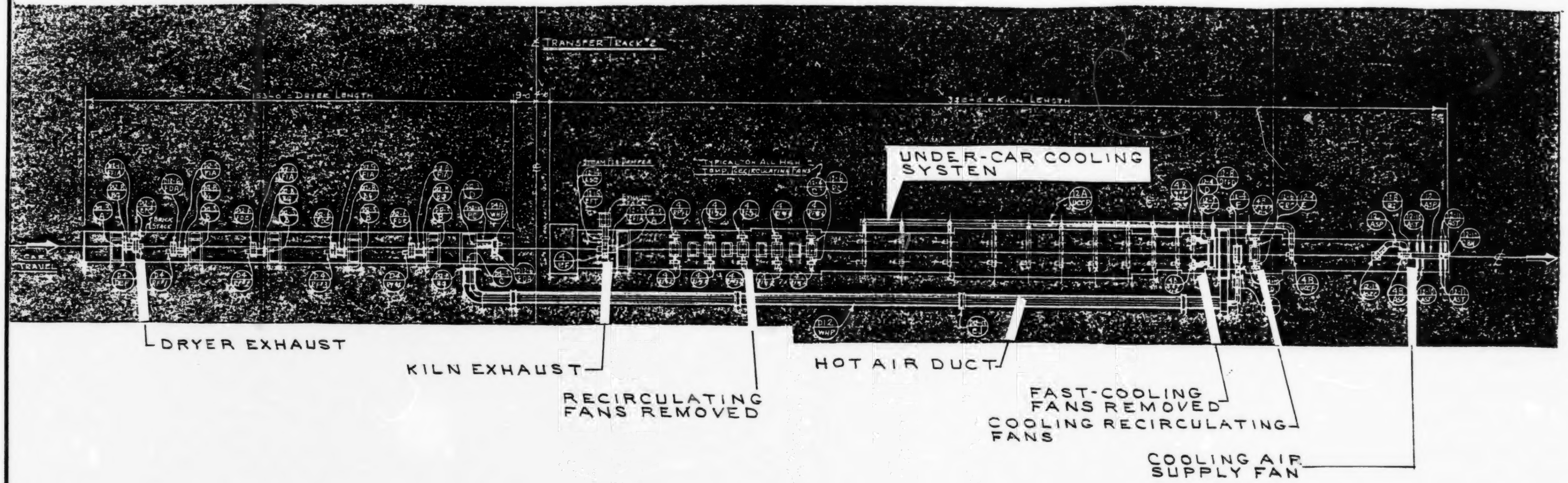


FIGURE 9 - PLOT PLAN OF KILN AND DRYER

A number of equipment deletions have been made from the kiln since it was installed. They are the following:

1. The air lock guillotine type door failed shortly after startup and was never repaired.

2. The automatic damper on the kiln exhaust fan has been disconnected. The fan operates with the damper in open position.

3. All of the recirculating fans in the recirculating section of the preheat zone have been removed.

4. Recirculating fans in the quick cooling section of the ware exit end of the firing zone have been removed and this section, in effect, decommissioned.

The following burner additions have been made on the kiln:

1. Five high velocity burners have been installed in the crown of the preheat zone recirculating section to replace the removed recirculating fans.

2. Original pipe burners in the crown of the firing zone have been replaced with high velocity burners.

3. Sidewall and crown North American 223G-3 nozzle mix closed excess air burners in the preheat zone have been replaced with high velocity burners. (A total of 14 in the sidewalls and 7 in the crown.)

All high velocity burners are North American 4442-3.

Burners in the firing zone remain the original North American 225-2 open-type nozzle mix dual-fuel burners. Most of the burners operate with fully open or near fully open registers. The registers have seized-up and cannot be readily adjusted.

Burner systems in the preheat and firing zones (i.e. burners and their associated fuel and air piping and controls), are similar to those described in Section 2.5.2 and shown on kiln drawings in Appendix F.

The condition of the tunnel kiln and dryer can best be described as being poor due to what appears to be lack of maintenance over several years. All temperature and relative humidity indicating instruments on the dryer are not in working order and there are practically no indicating instruments or controls in working order on the kiln. Kiln and dryer settings and adjustments of air and burner systems for the different products processed apparently were gained through experimentation and experience and what has been found to "work" is routinely repeated. Emphasis undoubtedly has been and is on obtaining production of products in quality and quantity. Consequently, there is a need to define the state of existing operations of equipment and processes, to identify and define associated problems and to design and implement an equipment and operating procedures upgrading program. Such a program in itself would inevitably result in reduced fuel use.

Clayburn Industries Ltd. manufacture primarily refractory bricks, insulating brick, acid brick, and some types of building brick, notably Giant Red, a hollow building block. Castables, plastics and mortars, and refractory associated products are also produced. Firing temperatures are higher and kiln schedules (i.e. car push rates) are lower for refractories than those for structural clay products. Hence, specific fuel consumption (i.e. fuel used per unit weight of product) is typically higher for a refractory than for a structural clay product such as face brick.

4.0 DATA COLLECTION

4.1 APPROACH AND METHODOLOGY

Tunnel kilns and dryers are as a rule designed and operating conditions and settings optimized for one specific type of product -- for example face bricks. A study of such a kiln and dryer for improvements of performance and thermal efficiency is relatively easy compared to that for the Clayburn tunnel kiln and dryer where operating conditions for a variety of diverse products must be considered. Since there is limited scope for adjustment of process conditions in a tunnelkiln compromises, usually in production rate and fuel use efficiencies, are necessary for some products in order to produce a satisfactory product.

The firing of four of Clayburn's line of products was selected for measurement of dryer and kiln operating variables for analysis of performance. The selection was based on production volume of each product, diversity of maximum firing temperatures, and products with particularly stringent firing requirements especially in the oxidation-preheat stage. The products selected were:

- medium duty firebrick
- Giant Reds (a red hollow building block)
- Insulating brick (Diatherm 17)
- Acid brick

Of these acid brick was further selected for collection of more detailed information for the preparation of air mass flow, moisture, and energy balances. Where quantitative values pertaining to these are given from hereon they refer to operations on acid brick unless stated as applying to other products.

Kiln atmosphere oxygen concentrations were measured with oxygen air analyzers. (Neatronics FEM, Teledyne 320P and Teledyne 990). Kiln and dryer tunnel atmosphere pressures were measured with Dwyer Magnehelic pressure gauges with ranges 0 to 0.25" (6.35mm) w.c., 0 to 0.5" (12.7 mm) w.c. and 0 to 2" (50.80mm) w.c. Temperatures of air and combustion gases were measured using dial and mercury filled thermometers. Relative humidities and humidity ratios were determined from dry and wet bulb temperature readings. Air flows were measured with use of a Pitot Tube. Temperature of kiln and dryer surfaces and temperature of ware were measured with a bimetallic type surface thermometer. A travelling thermocouple temperature profile through the kiln was obtained for acid brick using a Honeywell Servoline 45 temperature recorder and Type S thermocouple. The travelling thermocouple was located about 9 inches above the car top refractory and inside the rear one-half of the righthand side (when looking into the kiln entrance) tier of the setting. A thermocouple-to-recorder connecting wire of sufficient length was provided to be pulled by the car through the length of the kiln. The car schedule or push rate was used to determine the location of the car at any given time.

Natural gas consumption was obtained from instantaneous meter readings, i.e. by measuring time for flow of 100 ft.^{3} of gas and from operator's reading of the gas meter for a 24-hour period. From the latter, any gas usage by the predryer or shuttle kiln was subtracted. Neither of these methods is considered wholly reliable. Instantaneous meter readings do not account for variations in kiln heat demand. Operator's logs do not account accurately for shuttle kiln and predryer fuel uses -- for example the predryer gas consumption is only an estimate. The disconnected meter for the tunnel kiln should be repaired or replaced if accurate records of fuel consumption are to be maintained.

4.2 COLLECTED AND MEASURED FIELD DATA

For a listing of collected and measured field data see listing under 'Appendix C' in Table of Contents. References to tables from hereon with suffix 'C' refer to Tables in Appendix C (e.g. Table VIC).

Graphical illustrations larger than page size are referred to as charts which are compiled in Appendix E and listed under 'Appendix E' in the Table of Contents. The above tables contain information necessary for reading of the text and data for calculations in Appendix D and elsewhere in the text. Pitot tube readings and calculations of air flows are not included; measured air flows are summarized in Table I.

Engineering drawings for the tunnel kiln and dryer and shuttle kiln stiff mud predryer are found in Appendix F, G, and H respectively. The drawings, of course, are not complete files of drawings, but sufficient to illustrate physical aspects of equipment for purposes of this work.

4.3 TREATMENT OF DATA

Kiln prescribed (objective or design) crown temperatures, found in Table XVIIC (Appendix C), were used directly to plot design crown temperature profiles in Chart IE (Appendix E). Information from Tables IC to VIIC was used directly to plot kiln atmosphere oxygen concentration profiles found in Chart II and kiln pressure profiles found in Chart IIIE. The travelling thermocouple temperature profile for the tunnel kiln, shown on Chart IVE, was plotted directly from the temperature recorder chart.

Air flows in stacks and ducts, calculated from Pitot Tube data are summarized in Table I; calculated dryer heat balance data are summarized in Table II; calculated kiln heat balance data are summarized in Table III. Calculations are included in Appendix D.

5.0 ANALYSIS AND DISCUSSION OF TEST RESULTS

One of the ways, often the least costly, of reducing fuel consumption in dryers and kilns is to increase the rate of production since energy losses do not increase proportionally. Increasing equipment performance to achieve increased production then is a valid measure for increasing energy use efficiency.

5.1 TUNNEL DRYER

Air flow rates, temperature and humidity data for the dryer are summarized in Table I; surface temperatures appear in Table IXC; temperature of ware in process in Table XC; weights of clay and water in ware in Table XIC; air temperatures and moistures throughout the length of the dryer in Table XIC (illustrated graphically in Figure 10) and calculations for air mass flow, moisture and heat balances in Appendix D. The dryer heat balance is summarized in Table II.

An examination of dryer air supply and air exhaust quantities in Table I indicates a gross imbalance in the quantities of air supplied and exhausted. The quantity of air exhausted is in the range of 2.2 to 2.8 times the volume of hot air supplied from the kiln. The resulting high negative pressures in the dryer, measured in one instance to be 0.38" (9.65mm) W.C. at the charge end and 0.24" (6.35mm) W.C. at the exit end, result in high infiltrations of ambient air, mainly through charge and exit doors. The infiltered air serves no useful purpose. It is energy wasteful since in being heated to exhaust temperature it wastes 26.8 percent of the total energy input to the dryer (see Table II). Since dryer thermal efficiency is only 23.9 percent the energy thus wasted exceeds that for evaporating water. The low relative humidity of the exhaust air in the range of 5 to 15 percent (Table I) indicates that even at the low exhaust temperature of 120° to 189°F (49° to 87°C) the exhaust volume is overly large. However, because air supply

TABLE I: SUMMARY OF MEASURED AIRFLOWS IN STACKS AND DUCTS FOR KILN AND DRYER

WARE	AMBIENT AIR		DUCT-KILN TO DRYER			KILN EXHAUST STACK			DRYER EXHAUST STACK				COOLING AIR SUPPLY		
	Temp °F DB/WB	RH %	Temp °F	ACFM	SCFM (at 32°F)	Temp °F	ACFM	SCFM (at 32°F)	Temp °F DB/WB	RH %	ACFM	SCFM (at 32°F)	Temp °F	ACFM	SCFM (at 32°F)
Med. Duty Firebrick	58/48.5	50	630	10,640	4,802	375	48,610	28,640	149/95	15	16,630	13,440	93	7,370	6,560
Giant Reds			625	10,450	4,739	308	36,550	23,420	150/95	15	16,400	13,200	93	8,390	7,460
Insul. Brick Diatherm 17			450	11,325	6,123	312	44,420	28,310	120/		15,880	13,470	93	3,580	3,180
Acid Brick	80/62	35	590	12,172	5,700	340	43,730	26,890	189/100	5.3	16,750	12,700	93	6,690	5,950

TABLE II - DRYER HEAT BALANCE SUMMARY (ACID BRICK WARE)

Item	INPUT	OUTPUT AND LOSSES	
	1000 Btu/day	1000 Btu/day	Percent
Hot air from kiln	79,120	-	-
Ware and car top refractory and car steel	564	9,385	11.5
Water in ware	294	1,841	2.3
Evaporation of water	-	19,525	23.9
Exhaust air	-	39,158(1)	48.0
Surface heat losses	-	11,659	14.3
Unaccounted input	1,590	-	-
TOTALS	81,568	81,568	100.0

(1) Includes 21,853,000 Btu/day (26.8%) for heating infiltration air from ambient to exhaust temperature.

$$\text{Dryer thermal efficiency} = \frac{19,525,000}{81,568,000} \text{ X } 100 = 23.9\%$$

$$\text{Specific heat consumption} = \frac{81,568,000}{19,580} = 4166 \text{ Btu/lb. water evaporated (2333 kcal./kg)}$$

Note: Calculations for values in this table are contained in Appendix D.

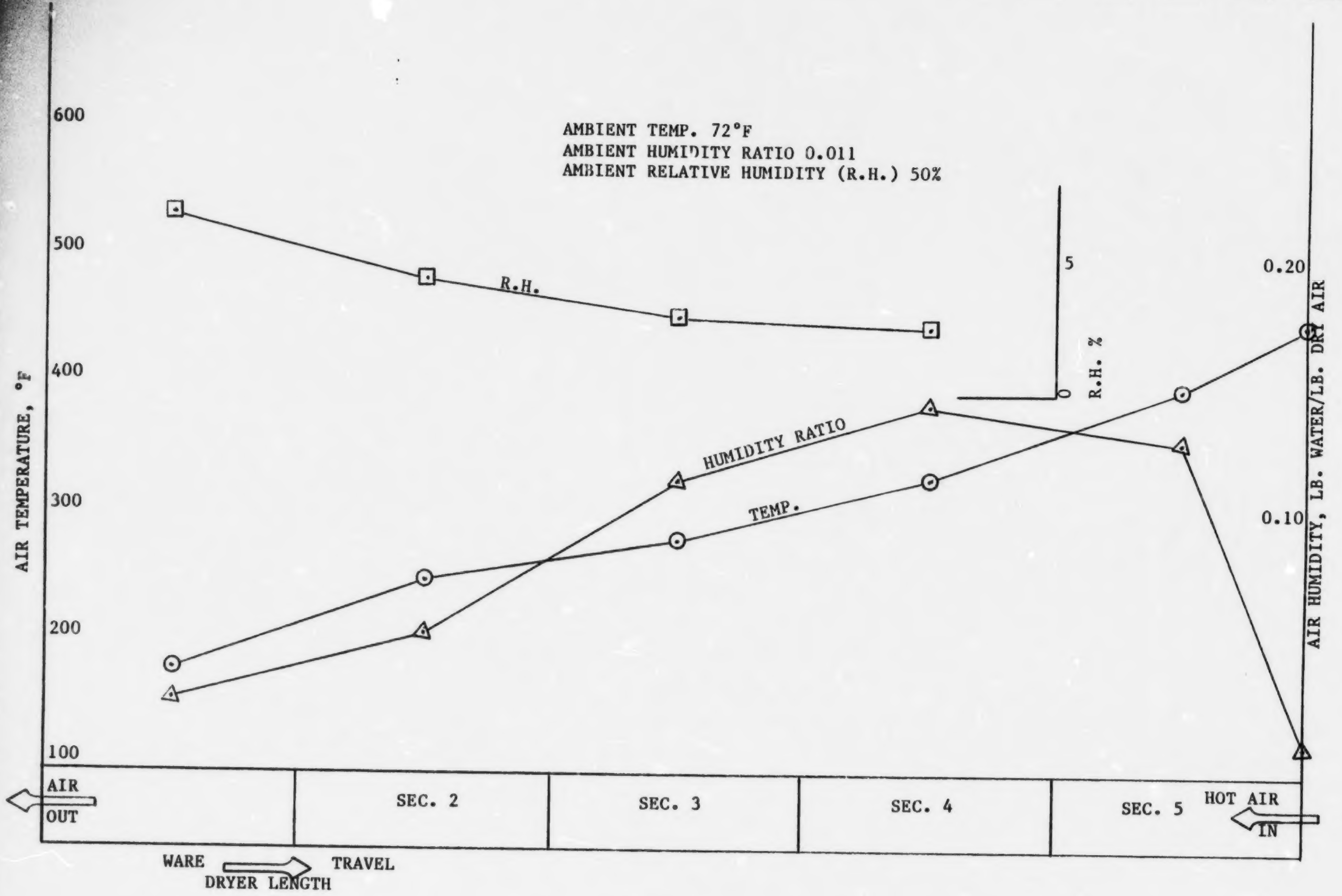


FIGURE 10
DRYER TEMPERATURE AND HUMIDITY PROFILES

to the dryer in this instance is also the energy source, the functions of heating and supply and discharge of air to control saturation of exhaust air cannot be adjusted separately. Replacing the hot air energy source by individual burners in the recirculating duct of each individual section would eliminate hot air transport heat losses and allow more precise temperature control throughout the dryer. Using this method a specific heat consumption of 1786 Btu/lb. (1000 kcal./kg.) has been reported. The specific heat consumption of the study dryer is 4166 Btu/lb. (2333 kcal/kg.).

If a quantity of exhaust air equal to the quantity of infiltrated air was recirculated to the inlet, in the case for acid brick, the new exhaust temperature would increase from 189°F (87°C) to an estimated 323°F (162°C) and the humidity ratio in the exhaust would increase from 0.0228 to 0.0418. If, alternatively, the quantity of exhausted air were decreased to equal the quantity of air supplied, the new outlet air temperature would be about 309°F (156°C) and the new humidity ratio would be about 0.0508. In the above temperature estimates it was assumed that all losses (e.g. surface heat losses) except stack losses would remain the same as at the 189°F (87°C) exhaust temperature. Hence the estimated exhaust temperatures are on the high side. Because of the low moisture loadings the exhaust temperature would be unnecessarily high for moisture removal and hence the dryer could then operate with a lower heat supply.

In two instances surface temperatures of ware leaving the dryer were measured at 338°F (170°C) and 392°F (200°C). Ware can enter the kiln safely, without incurring condensation of flue gas moisture as long as its temperature is above 212°F (100°C). The dryer may be viewed as functioning also as a preheater for the kiln and since ware must be preheated in the kiln in any event the high dryer ware exit temperature could be viewed as having some advantage if the products are not cooled before transfer to the kiln. However, sensible heat in the ware is lost here in another way. Ware entering the kiln at 338°F (170°C) was found to have cooled to 194°F (90°C) by air infiltrating at the charge door by the time the car had travelled about 2 1/2 car lengths from the charge door toward the exhaust fan located about 20 feet (6m) away. Preheating in the dryer then appears to be effectively cancelled out in the first part of the kiln. As a rule, it is preferable to use kiln gases to preheat ware above 212°F (100°C) rather than hot air from the kiln cooling zone which is clean and which usually can be utilized more effectively elsewhere (e.g. combustion air, space heating, predrying). Kiln gases because of their combustion products content are limited in application. However, because of high air infiltration into the kiln preheat zone, in this instance, it may be feasible to use kiln exhaust gases direcly for drying as dilution with infiltrated air lowers their dew point temperature and reduces concentrations of any contaminants that may be present.

Kiln cooling zone hot air is utilized at a severe penalty for hot air transport to the dryer. For the hot air to arrive at the dryer, after travelling through the 300 feet (91.4m) of 36" (0.91m) diameter duct, at 570°F (299°C) it must leave the kiln hot air takeoff at 740°F (393°C). In supplying 79,120,000 Btu/day (83,477 MJ/day) in form of hot air to the dryer 106,642,000 Btu/day (112,515 MJ/day) must leave the kiln for a 26,664,000 Btu/day (28,133 MJ/day) duct heat loss which is 33.7 percent of the net heat supplied. Other heat losses are 6,115,000 Btu/day (6,452 MJ/day) from dryer brickwork (i.e. dryer body) and 5,544,000 Btu/day (5,849 MJ/day) from dryer supply, exhaust and recirculation fans and their immediately associated ductwork all of which are bare steel. The air supply duct from the kiln has about 1 1/2" (3.81 cm) thick fiberglass blanket insulation. Better insulation is needed to reduce surface losses.

An insulation supplier's energy reduction analysis is included with calculations in Appendix D. Insulation of the kiln-to-dryer air supply duct and of the fans and their associated ductwork with 4" (102 mm) to

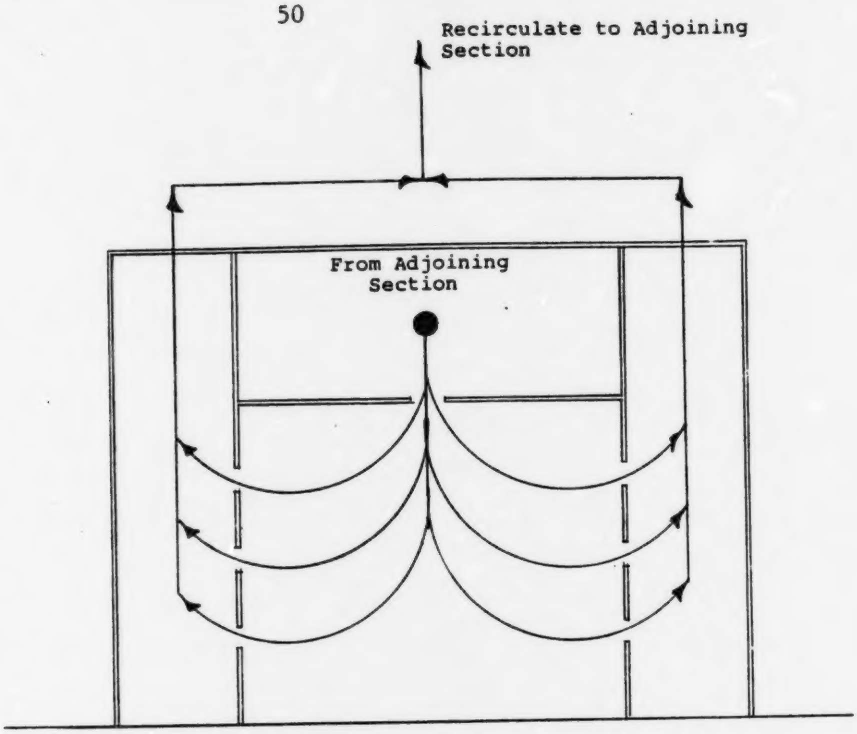
6" (152 mm) thick fiberglass insulation is economically attractive with payback periods of less than 1.2 years. Insulation of the dryer roof should also be considered. Sealing of cracks in doors and walls would return immediate benefits at low cost. The above savings would only result of course, if there was a direct saving in natural gas use.

The original design of the dryer appears to have overlooked two phenomena common to the behavior of hot and humid air which manifest themselves in a countercurrent flow tunnel dryer as follows:

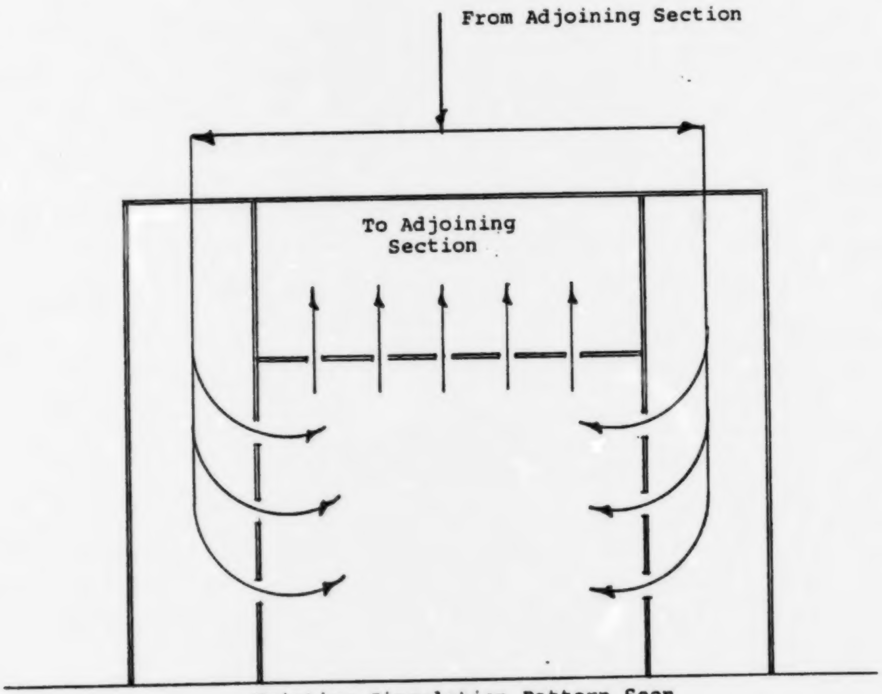
1. In the hot zone of the dryer (extending from the ware exit and hot air entrance end) recirculating units should counteract the upward movement of air which is proportional to the difference in density of dryer air and ambient air which increases toward the dryer ware exit. Otherwise stratification would occur with a strong flow of hot air under the dryer ceiling towards the exhaust fan at the dryer ware entrance end.

2. At the air exhaust (ware entrance) end of the dryer the hot air tends to remain under the ceiling while the now cooled humid air of higher density tends to stay in the lower zone of the tunnel. The dryer exhaust takeoff should then not be via the roof but from the lower half of the tunnel.

If the circulation pattern is in reverse, as is the case here, preferential drying and heating of ware in the upper portion of the tunnel is liable to occur. Existing and recommended air circulation patterns are illustrated in Figure 11. Circulation patterns in the dryer for each section could be reversed to that recommended by alteration of masonry work in the ceiling compartment of each section and reducing the number of longitudinal slits in the ceiling to one central slit of greater width. The supplier of the dryer, it appears, has now changed his design to the preferred circulation patterns described.



Preferred Circulation Pattern Seen In Tunnel Cross-Section



Existing Circulation Pattern Seen In Tunnel Cross-Section

FIGURE 11 - EXISTING AND RECOMMENDED TUNNEL DRYER AIR CIRCULATION PATTERNS

Moisture balance on ware indicates an evaporation of 19,580 lb./day (8,881 kg/day) while a moisture balance on air indicates a removal of 22,020 lb./day (9,988 kg/day), the two figures being within 12.5 percent of each other. In calculating the moisture balance it was assumed that in the predryer no evaporation of water occurs but that the ware is simply heated up to 95°F (35°C). The moisture balance on air appears to indicate that this assumption was essentially correct and that only a small quantity of water, at best, is evaporated in the predryer. The operation of the predryer is puzzling in that there is no measurable exhaust of humid air which would indicate that it functions only as a conditioning chamber. Nevertheless, it requires 24,000,000 Btu/day (25,322 MJ/day) supplied by a direct natural gas-fired air heater. Since the predryer temperature is predominantly about 120°F, about one half of its present energy requirement could be met by the dryer exhaust air since its moisture content is low, and the balance by fresh hot air from the kiln. If the present kiln-to-dryer duct heat loss could be decreased by insulation, the energy saving would be sufficient to provide the additional predryer heat requirement without increasing the volume or temperature of the hot air leaving the kiln and without decreasing the amount of heat presently supplied to the dryer.

The dryer hot air supply temperature of about 570°F (299°C) appears high in view of a feasible 240°F (116°C). There seems little point in raising the temperature of the ware to 338°F (170°C) (i.e. preheating) in the dryer if it is cooled to 194°F (90°C) or less in the section of kiln ahead of the exhaust fan prior to being reheated again as previously explained. A counterargument could be made that it is essentially to drive out all of the water from the ware prior to entering the kiln, but once the ware is above 212°F (100°C) it can be safely dried with kiln flue gases in the kiln. Only the question of drying rate remains. However, in the latter stages of drying, a high heat rate is usually not detrimental. Furthermore, the maximum dryer temperature would not be reached with the third or fourth car from the kiln charge door, provided air infiltration through the charge door is reduced, which is comparable to the highest ware temperature being attained in the last four-car section of the dryer. The lowering of dryer ware exit temperature would free some hot air for use in the predryer and other uses if they can be found.

In considering heat conservation for the dryer it should be recognized that hot air from the kiln will always be available and that there is no point is displacing its use or loss if it cannot be effectively utilized elsewhere to reduce fuel costs. Any measure taken to increase tunnel kiln performance, such as increasing the amount of primary heat supplied to the preheat zone and more efficient cooling, would result in an increased quantity of hot air becoming available. In this instance it is obvious that the dryer, for purposes of drying alone and not preheating, is over supplied with heat. Therefore, if a use cannot be found for the heat surplus, measures for heat recovery and optimization of dryer performance are economically pointless.

5.2 TUNNEL KILN

Air flow rate and temperature data are summarized in Table 1. Field data are compiled in Appendix C; graphical treatment of such data is included in charts in Appendix E. Calculations appear in Appendix D. The kiln heat balance is summarized in Table III.

5.2.1 Prescribed Firing Curves

Prescribed firing curves shown on Chart 1E (Appendix E) were plotted from prescribed crown thermocouple temperatures (which are kiln gas temperatures at the crown of the kiln) for each product found in Table

TABLE III - KILN HEAT BALANCE SUMMARY (ACID BRICK WARE)

ITEM	INPUT	OUTPUT AND LOSSES	
	1000 Btu/day	1000 Btu/day	Percent
Provision by natural gas	384,060	-	-
Provision by ware charge	9,927	-	-
Provision by cooling air	2,014	-	-
Flue gas loss	-	198,973(1)	50.2
Heat recovery - hot air to dryer	-	106,642	26.9
Losses due to discharge of ware and cars	-	2,526	0.6
Radiation and convection losses	-	32,536	8.3
Unaccounted losses (which would include latent heat of combined water, endothermic losses and bottom car cooling losses)	-	55,324	14
TOTALS	396,001	396,001	100.0

(1) Includes an estimated 175,749,000 Btu/day (44.4%) to heat infiltration air to exhaust temperature of 340°F.

Specific heat consumption = 384,060,000/10,472 X 12 X 0.954 = 3204 Btu/lb.

Approx. kiln thermal efficiency =

$$\frac{\text{Unaccounted Losses + Latent Heat of Mechanical Water}}{\text{Total Heat Input}} \times 100$$

$$= \frac{35{,}640 + 19{,}684 + 19{,}525}{396{,}001} \times 100$$

= 19%

Note: Calculations for values in this table are contained in Appendix D.

XVIIIC (Appendix C). The firing curves did not originate from rigorous laboratory testing; they were established directly through experience with kiln operation. That being the case they can readily be attained in day to day operation of the kiln as evidenced from operator's logs, some examples of which are compiled in Table XIXC.

Tunnel kilns are relatively inflexible in adapting to different schedules for different products. Process stages and conditions then are unlikely to be optimum for any one product in terms of production rate and fuel consumption. Although the kiln supplier (Harrop) was requested to design the kiln in 1964 for dry press refractories, stiff mud refractories and dry press face brick this was at a time of low energy costs. Deletions of recirculating fans in the preheat zone and quick cooling, draft control and charge end air lock from the kiln since it was built have detracted further from optimum performance.

Since laboratory or theoretical firing curves for the four study products are not available there is no absolute reference for judging the appropriateness of the prescribed curves or process to the product or for identifying areas of potential energy savings through increases in production rate. However, there are some obvious points that should be mentioned.

1. The air temperature at thermocouple No. 2 is in the range of 100°F (38°C) to 200°F (93°C) which would result in cooling of preheated ware entering from the dryer as explained earlier in Section 5.1. The accelerated decline in kiln gas temperature between thermocouples No. 2 and No. 7 is suspected as being partially due to infiltrated air, rather than solely due to accelerated heating of ware.

2. Accelerated quick cooling is possible in the length of kiln between thermocouple No. 31 and No. 33 to a temperature of 1200°F

(649°C). This does not occur because quick cooling fans have been removed and quick cooling is no longer in effect. In the quick cooling section, as originally designed, recirculating fans drew air from the uppermost part of the kiln. When a kiln is back-drafting flue gases from the furnace tend to flow into the cooling zone along the bottom of the crown. There is a strong possibility that the fans were then drawing very hot flue gases which has resulted in their requiring constant maintenance and premature failure. Present-day designs of quick cooling systems utilize a mixture of ambient air and kiln gases such that the fans handle gases at a temperature of about 1050°F (566°C).

3. Cooling rate between temperatures of 1200°F (649°C) and 600°F (315°C) should be slow with fast cooling again being possible from 600°F (315°C) down to ambient. Cooling rate from maximum firing temperature to 600°F (315°C) remains more or less the same. Instead of increasing below 600°F (315°C) as is possible, the cooling rate slows down. The temperature at thermocouple No. 43 could safely be near ambient for more efficient cooling and heat recovery.

4. To obtain higher temperature in the early part of the preheat zone necessary for faster carbon, sulfur, and binder burnout, leap-frog circulation along with any necessary supplementary heat in the recirculating section would be beneficial. Leap-frog circulation means taking air from a hotter zone and transferring it down the air stream to a cooler zone. A higher temperature in the early stages of oxidation would increase both oxidation rate and effective time for oxidation to occur. Oxidation presently is the main impediment to a faster kiln schedule for medium duty firebrick.

5. The firing zone dwell time, or soak, appears overly long and has a pronounced shift downstream (with respect to product flow) with

high temperatures extending into the cooling zone. Control thermocouples, if moved upstream one or two thermocouple positions would shift the curve peak upstream where heat can be better utilized in the preheat zone (i.e. as opposed to cooling zone).

An idealized firing curve is superimposed on Chart IE to reflect all of the above comments.

5.2.2 Variations From Prescribed Firing Curves

A travelling thermocouple temperature profile for acid brick was obtained with a travelling thermocouple located near the bottom of the setting as described in Section 4.1. The travelling thermocouple profile is plotted on Chart IVE along with prescribed and actual crown temperature profiles to illustrate variations in kiln atmosphere temperatures between the top and bottom of kiln throughout its length.

Initially, between thermocouple number 2 and 5, temperatures inside and at the bottom of the setting are higher than crown temperatures due to the more rapid cooling of the outside of the setting by air infiltrating through the charge door as described in Section 5.1. Between thermocouple number 5 and 10, in about the first two-thirds of the recirculating section length, temperatures inside and at the bottom of the setting are lower than crown temperatures due to the preferential movement of hot gases in the upper part of the tunnel and cooling of the lower part of the setting by air infiltrated from the compartment below car decks, as explained in Section 5.2.4, which largely negates the effect of crown burners which tend to circulate hot air downwards into the centre aisle between the two tiers of the setting. In the latter two-thirds of the recirculating section temperatures at the bottom of the setting are higher than crown temperatures due to decreased air infiltration (due to decreased negative pressure) and the increased effect of crow burners in heating the centre and bottom of the setting. For the remainder of the profile, temperatures inside the setting in the lower part of the tunnel are generally lower than temperatures in the upper part of the tunnel. This is as expected for the burner section of the preheat zone and the firing zone and is typical for most kilns. However, in the cooling zone the reverse should be true, but here it is not. The explanation offered for this anomoly is the reverse travel of hot gases from the firing zone counter to that of cooling air from the kiln ware exit with replacement of gases leaving the firing zone by ambient air entering at the hot air take-off ports at which ambient air enters the tunnel to cool by dilution hot air that is drawn off to the dryer. Literature reports indicate that this is possible and does occur in some kilns. It is the hot air flow that would register the higher temperatures at crown thermocouples in the cooling zone. It would also explain the relatively flat pressure profile, measured at about mid-height in the cooling zone, indicating essentially no air flow.

Temperature differences between travelling and crown thermocouples in the burner section of the preheat zone, the firing zone and the cooling zone are not large, indicating potential for higher production rates. Impediments to higher production rates appear to reside in the preheat zone, particularly in the flue section and the recirculating section. Problems in the cooling section just described, can be corrected by applying a higher positive cooling air pressure at the kiln ware exit and by increasing cooling air flow. Higher temperatures and attendant higher production rate capabilities in the preheat zone should be possible with the following measures:

a) Reduction in quantity of infiltrated air to the flue section and recirculating section.

b. Reduction in excess air to burners in the burner section.

c. Improved recirculation of kiln gases in the recirculating section.

d. Possibly more burners in the recirculating section and in the first one-half of the burner section.

Oxidation of impurities in the clay occurs in the temperature range of 660 to 1740°F (350 to 950°C) and is a function of temperature, time and oxygen concentration. Therefore, the sooner the highest temperature possible is attained in this range in the preheat zone the more rapidly will oxidation proceed and be completed earlier.

5.2.3 Kiln Atmosphere Oxygen Concentrations

Kiln atmosphere oxygen and air concentration profiles shown on Chart IIE were plotted from field data shown in Tables IC, IIIC, VC and VIIC and summarized in Table XVIIC (Appendix C).

There are two more or less separate kiln systems. The preheat and firing zones through which gases travel from the charge end of the firing zone to exhaust at the flue section; and the cooling zone through which cooling air travels from the kiln exit to the relief ports from which it is withdrawn to the dryer. The buffer zone, flashing zone and quick cooling section in this kiln (because quick cooling has been eliminated) together function as a buffer zone through which some cooling air passes into the firing zone in the lower part of the tunnel and a quantity of flue gases pass to the relief ports in the upper part of the tunnel. Of the 5700 scfm (161.4 m^3/min) of hot air withdrawn to the dryer, 407 scfm (11.52 m^3/min) was calculated to be flue gases - hence the quantity of backdrafted flue gases is relatively low.

Kiln pressure profiles indicate that only the preheat zone is under negative pressure with the firing zone being under slightly positive pressure (see Chart IIIE). The increase in oxygen content in the kiln atmosphere stream from the exit to charge end of the firing zone (2.6 to 8.5%) is attributed largely to seven high velocity (H.V.) burners in the crown which are operated wide open to air at 24 osi (10.34 kPa) and 2.5" (63.5 mm) w.c. P on gas. The excess air thus supplied to the crown burner is about 100 percent. It is unnecessary and wasteful of fuel to operate the crown burners at high excess air even for purposes of inducing air circulation. The high nozzle velocity in H.V. burners is created by the expansion of combustion gases in the firing chamber by a factor of about 6 which is achieved under stoichiometric conditions. At 100 percent excess air the mixing effect is less because of lower nozzle velocity.

Furthermore, the firing zone should be operated with as little air as possible. There is no point in bringing in preheated air via the burners which must be heated to firing zone temperatures by burning additional fuel. The use of H.V. burners in the firing zone is questionable in the first place if ostensibly for mixing to increase convective heat transfer. Above 1472°F (800°C) the effect of convection in relation to radiation is thought to decrease sharply to less than 10 percent of total heat transfer.

The preheat zone atmosphere oxygen concentration, in the rar of 14 to 20 percent, in the oxidation temperature average of 572°F (300°C) to 1652°F (900°C) is unnecessarily high. An oxygen concentration of about 13.5 percent representing 161 percent excess air would be sufficient. The high oxygen concentration is undoubtedly partially due to air infiltration caused by the high negative pressure in this zone. Again, for reasons already given, and because of the high air infiltration there is no need to operate crown burners in the preheat at high excess air levels.

5.2.4 Kiln Atmosphere Pressures

Kiln atmosphere presure profiles shown on Chart IIIE were plotted from field data shown on Tables IIC, IVC, VIC and VIIIC (Appendix C).

The high negative pressure in the preheat zone is due primarily to the narrow width of side gaps (relative to side gaps in the firing zone). In the design of the kiln the side gap width was reduced apparently to force the air through the setting (or charge) and thus overcome the difficulty of heating the interior of the pack. Attempts to penetrate the setting in this way usually have only led to high resistance forces, high negative pressures, high air infiltration and high air flow speeds in the side gaps. Of the total exhaust volume of smoke gas (term used to denote kiln flue gas) 88.3 percent is calculated to be air with the balance being products of combustion. A practical solution would be to set wares in longitudinal tiers, in separate small pillars or by accepting low setting heights. Another approach would be to provide mechanical recirculation and decrease draft. This would entail replacing the original fans in the recirculation section. Recirculation would lower smoke gas exhaust temperature and volume and thus save fuel.

The kiln is operated without an exit door (although it originally had one). Air from the cooling fan is introduced into the exit end of the kiln with the purpose of creating a thrust-effect to force flow of air into the cooling zone. This results in some pressure build-up which acts to blow hot air out of the kiln with loss of some recovered heat. Pressure curves for the cooling zone indicate only a weak flow of air which for firebrick appears to be in the wrong direction. This was confirmed by a smoke bomb test. Drawing off more hot air to the dryer to improve flow of cooling air would also increase backdrafting from the firing zone. An exit door with a variable speed fan would be beneficial in increasing the flow of cooling air, preventing the escape of hot air from the exit and decreasing or eliminating the backdrafting. A curve is superimposed on Chart IIIE to indicate what the effect of an exit door might be.

The firing zone furnace pressure is only slightly positive which is suitable for the type of burners in use.

The neutral or zero pressure point is at or near the charge end of the firing zone which is where it should be.

An examination of pressure readings in Table IVC and VIIIC indicates infiltration of ambient air through car side seals into the negative-pressured circulating section of the preheat zone and exfiltration of kiln air through car side seals in the positive-pressured recirculating section of the cooling zone. Note that in the preheat zone recirculating section, pressures are higher just above the car decks than in the upper part of the tunnel, whereas, in the cooling zone section pressures are higher in the upper part of the tunnel than just above car decks with flow in both cases being from high to low pressures. Visual examination of car side radiation shields indicated that clearances may be greater than need be due to wear hence their effectiveness as convection seals would be low.

The present high density car top refractory and tunnel seal lips, once worn would have variable clearances throughout the length of the kiln. An examination of the interior of the kiln during a shutdown found the refractory tunnel seal lips to be broken and badly eroded. The sand convection seal may also be at fault. Since the present high density refractory car tops in leaving the kiln are a source of heat loss, it may be expedient to retrofit the cars with low thermal mass refractory, and in this way obtain new car side seals as well. Heat loss in car top refractory is estimated to be in the range of 425,000 to 1,000,000 Btu/day (448 to 1055 MJ/day).

A study of Harrop dwg. No. 713-4 (Appendix F) shows an underground duct with an intake on the kiln centerline near buckstay No. 7 and two outlets in the hollow sidewalls communicating with the inside of the flue section between buckstay No. 4 and 5. The purpose of this arrangement is apparently to have the kiln exhaust fan draw air from the compartment under the car decks for the purpose of cooling the steel structure of cars. Ambient air for cooling enters the end of the compartment at buckstay No. 15 (at which point it ends since beyond that in the preheat burner section and firing zone kiln walls do not go down to the floor in order to provide better cooling needed in hotter sections of the kiln). The two duct outlets referred to above are dampered shut so no air is drawn to induce air flow for car cooling. This is not detrimental at present as sufficient cooling of cars is provided by air infiltrating through car seals as explained earlier. The extent of this air infiltration is confirmed by the strong draft that exists at the end of car underdeck compartment at buckstay No. 15. If pressure in the compartment could be maintained at a negative value near that prevailing in the kiln, air infiltration into the kiln could be reduced considerably. This can to a large extent be achieved by constructing an under-car dam between buckstay No. 13 and 15 as none exists at the exit end of the kiln and exhausting the compartment either by means of the kiln exhaust fan (which would need that dampers at the two duct outlets be open) or by means of a separate fan.

5.2.5 Kiln Heat Balance

Calculations for the heat balance, summarized in Table III, appear in Appendix D. Unaccounted heat losses amount to 14 percent of the total output and losses. These would include losses due to endothermic irreversible chemical reactions, latent heat of combined water and bottom car cooling losses. As a generalization, given here for purposes of comparison, the heat input to a tunnel kiln is utilized as follows:

Flue gas or smoke gas losses	25 to 35%
Heat recovery	40 to 60%
Radiation and convection losses	8 to 10%
Unaccounted losses	about 5%

Not surprisingly, because of high air infiltration in the study kiln, flue gas losses comprise 50.2 percent of input. Heat recovery constitutes only 26.9 percent of input as compared to 40 to 60 percent for reasons of the disproportionately high flue gas loss. For the same reason, and because of the condition of the kiln, the radiation and convection heat loss of 8.3 percent is felt to be diluted by the disproportionately high flue gas loss. Also, the heat loss estimate is judged to be conservative.

Specific heat consumption when producing acid brick is 3204 Btu/lb. (7453 kJ/kg). When producing medium duty firebrick this same figure is 2585 Btu/lb. (6013 kJ/kg). Approximate kiln thermal efficiency on acid brick defined as,

$$\frac{\text{Unaccounted losses and latent heat of mechanical water}}{\text{Total heat input}} \times 100$$

is 19 percent.

5.2.6 Kiln Air Balance

Calculations for the kiln air balance are found in Appendix D the results of which are summarized below.

1. Preheat and Firing Zone Air Systems

Gases leaving = gases exhausted + gases backdrafted

Gases exhausted: 26,890 scfm (761.5 m^3/min) - Table 1

Gases backdrafted:

O_2 conc. in hot air takeoffs:	19.5%
O_2 conc. in flue gases at stack:	2.6%
O_2 conc. in cooling air:	20.8%
Volume of hot air leaving:	5700 scfm (161.4 m^3/min) - Table 1

Let V = volume of combustion products backdrafted,

Then,

$$2.6\ V + 20.8\ (5700 - V) = 5700 \times 19.5$$

Solving,

$$V = 407 \text{ scfm } (11.52\ m^3/\text{min})$$

Gases leaving = 26,890 + 407 = 27,297 scfm (773.0 m^3/min)

Gases entering = Excess air supplied by H.V. burners + products of combustion + infiltered air where infiltered air includes air entering firing zone from cooling zone.

Gases entering = Gases leaving = 27,297 scfm (773.0 m^3/min)

Substituting calculated values,

$$27{,}297 = (61{,}800 + 169{,}900)\ \frac{492}{535} + \text{Infiltration air}$$

Infiltration air = 23,750 scfm (672.6 m^3/min)

The infiltrated air must be heat to the exhaust temperature of 340° (171°C) needing a heat input of 175,749,000 Btu/day (18,543 MJ/day) which comprises 88.3 percent of the total flue gas loss of 198,973,000 Btu/day (20,993 MJ/day).

2. Cooling Zone

An air balance on the cooling zone could not be provided because the quantity of ambient air entering the relief ports to cool hot air by dilution for the dryer, the quantity of cooling air that leaves the kiln exit, and the quantity of cooling air entering the firing zone could not be measured.

2.5.7 Burners and Combustion Control

Burner performance data sheets are compiled in Table XXIC (Appendix C). Burner control systems are similar to those illustrated in Figure 6.

Recapitulating, the kiln burner complement is as follows:
Preheat Zone

- 5 crown H.V. burners in recirulating section
- 7 crown H.V. burners in burner section
- 14 sidewall H.V. burners in burner section

Firing Zone

- 7 crown H.V. burners
- 38 sidewall North American No. 225-2 open-type nozzle mix burners whose maximum capacity is 200,000 Btu/h. (with shutters closed).

All H.V. burners are North American No. 4442-3 (see Table XXIC) whose maximum capacity is 3540 But/hr. (8234 kJ/hr.) 16 osi (6.89 kPa) air supply.

For reasons explained in Section 5.2.3, all H.V. burners should be operated on stoichiometric fuel-air ratio. The mixing effect on kiln atmosphere will improve rather than deteriorate in going from excess air to stoichiometric ratio firing.

There is a strong possibility that the firing zone sidewall burners are operating fuel rich. The manufacturer recommends 0" W.C. gas pressure at the burner for all air pressures. Measured air and gas pressure on two occasions for different products were:

Firebrick: air 9.5" (241 mm) w.c., gas 2.5" (63 mm) w.c.
Acid brick: air 11" (279 mm) w.c., gas 3" (76 mm) w.c.

At the above air pressures the burners would operate at about 60 percent of capacity with shutters closed. With shutters fully open burner capacity doubles. There is no need then to operate the burners with shutter fully or partially open and incur radiant heat losses from flames estimated to be of the order of 6,000,000 Btu/day (6330 MJ/day). Cracks in the brickwork surrounding the burners incur an additional radiant heat loss estimated at 5,000,000 Btu/day (5275 MJ/day). The firing zone sidewall burners are in poor condition and the shutters are not operable so no corrective measures can be taken by closing them.

About 38 North American No. 223G-3 sealed-in nozzle mix burners would have been removed from the preheat zone in changing over to H.V. burners. Each has a maximum capacity of 3,540 Btu/hr. (8234 kJ/hr.). Using these burners to replace the open type burners presently in the firing zone would decrease radiant and convection heat losses and improve the air-tightness of the firing zone furnace. New H.V. burners would, of course, be preferable.

A strong odour of natural gas could be detected near the firing zone burners and in some instances ignitable leaks were found. Such leaks occurring continuously could amount to a considerable loss of fuel - a loss which could easily be corrected by simple routine maintenance practices.

The burner control systems are of types which are standard for tunnel kilns in the heavy clay products industries (see Figure 6). Relocation of the two control thermocouples or the two control groups in the firing zone should be considered for reasons explained in Section 5.2.1.

In theory, hot air could be utilized much more effectively as preheated combustion air (rather than as a heat source for the dryer) capable of operating with 30 to 40 percent excess fuel. Such burners, however, have not been perfected to the point of being widely applied. Where high velocity burners are used in the firing zone the practice generally is to supply about 15 percent of the combustion oxygen requirements from the cooling zone.

The kiln supplier, Harrop Industries Inc., markets a pipe burner for use in the firing zone of their tunnel kilns. The burner is designed for each kiln and is claimed to cost only a fraction of the cost of a high velocity burner. Harrop claim that the burner is in effect a high velocity burner and capable of operating 30 to 40 percent fuel rich.

5.2.8 Potential For Heat Recovery From Kiln Exhaust

In cooling 26,890 scfm (761.5 m^3/min) of kiln exhaust gases (comprising essential air) from 340°F (171°C) to 240°F (116°C) in an air-to-air heat exchanger there is potential for recovering about 76,000,000 Btu/day (80,186 MJ/day) with equal flows of supply air and flue gases. Supply air exit temperature for equal flows would be about 100°F (38°C) above entering temperature. A relatively high flue gas exit temperature of 240°F (116°C) is selected because of potential for SO_2, SO_3 and possibly fluorine being present in the exhaust.

Heat recovery from kilns is plagued by finding suitable materials for the usually corrosive flue gases and finding a use for the recovered heat. Glass has been reported to be corroded by hydrogen fluorine in the flue gases. Teflon covered tubular exchangers have had some success but are costly.

Hot air from the cooling zone can be fully utilized by passing more of it into the firing zone as combustion air (than is at present) and feeding the balance into the preheat zone. Such a scheme would deprive the dryer of a direct heat source from the kiln. Heat recovered from flue gases then can be utilized in the dryer supplemented, if necessary, by direct heating with natural gas by means of a burner installed in the dryer air supply plenum. One advantage of this scheme would be that the high heat losses incurred in transporting the hot air from the kiln cooling zone to the dryer would be avoided. Also, then, heat supply and air supply could be controlled more independently.

5.3 PREDRYER AND SHUTTLE KILN

5.3.1 Predryer

No measurable flow could be found in the predryer exhaust stack in two separate tests on two different products being dried. An examination of the predryer air circulation equipment showed that no exhaust of air was possible through the intended exhaust stack because the stack was connected to a fan suction duct which normally would be under negative pressure and the absence of any positive means for make-up air supply. As a result the stack serves as an intake for any make-up air for one of two circulating fans. The second fan has a stack connected to its suction duct apparently ostensibly as an air intake. Both circulating fans need make-up air because of the high exfiltration rate from the predryer at charge and exit doors. A smoke-bomb test confirmed both the absence of any discharge from the exhaust stack and the high exfiltration rate. The exfiltrated air appeared to leave the predryer without passing through the settings and hence its heat intended for drying would be wasted.

The natural gas consumption of the predryer provided by operating personnel is about 24,000,000 Btu/day (25,322 MJ/day). Use of natural gas for the predryer could be displaced by energy conservation measures at the dryer namely, insulation of the hot air supply duct and dryer fans and ducts, which would save about 31,000,000 Btu/hr. (32,707 MJ/day) in form of hot air exhaust from the dryer which could be directed to the predryer make-up air supply. Alternatively, hot air could be provided directly to the predryer but an additional 160 ft. (48.77 m) of duct would be needed. However, the latter has an advantage in that it would pass alongside the dryer (although in a larger duct) and allow hot air to be introduced into the dryer at say, two or three points (by connection to recirculating fans) thus providing a facility for control of the temperature profile throughout the length of the dryer.

The air circulation pattern in the first one-half of the predryer (from the charge door) is as shown on the first diagram in Figure 11 which is preferred. In the second one-half of the predryer the circulation pattern is as illustrated in the second diagram in Figure 11 - which is less effective and should be changed. The slot exit and entrance velocities are low and could be increased by narrowing the slots and possibly power supplied to the fans. Review of the entire predryer design prior to connection of a hot air heat source is advisable. Since, for example, humidity control is important during the first stage of drying, some means of controlling humidity may be necessary.

5.3.2 Shuttle Kiln and Dryer

The manufacturer, Bickley Furnace Inc., was asked to provide an indication of scope for upgrading shuttle kiln and dryer combinations of the kind and age installed at Clayburn Industries Ltd. and any changes in design of comparable present-day equipment. His reply is found in Appendix H. According to the information received, new kilns are insulated with ceramic fiber refractories, are available with stack/

convection type recuperators for preheat of combustion air, and have microprocessor controls for excess air.

Recuperators alone for the shuttle kiln would cost $74,000 (U.S.) - two recuperators each of 11,000,000 Btu/hr. (11,606 MJ/day) capacity would be required. The supplier indicated that a proposal study for one client in the U.S. Northwest showed that an installation on such a shuttle kiln was not economically feasible because high flue gas temperatures prevailed only during the relatively short soak period (i.e. hold period at highest firing temperature). In view of this advice heat recovery for the shuttle kiln was not investigated further.

6.0 FUEL USE REDUCTION PROGRAM

6.1 INTRODUCTION

In considering fuel use reduction alternatives for the tunnel kiln and dryer practical restraints imposed by the age and condition of the equipment, technology applied in their original design, and remaining useful life must be carefully assessed. For energy heat loss reduction measures there must be a useful application resulting in fuel saved. There is no purpose to be served, for example, in reducing the use of heat already being recovered from the cooling zone in the form of hot air if in the end the energy saved finds no useful application that reflects directly in a fuel saving.

Although, heat losses can be decreased by sealing leaks, providing better insulation, improving combustion efficiency and controlling infiltration air, the results of these improvements will usually be less than from an increase in production capacity. Therefore, increasing production is synonymous with reducing fuel use. Determining heat losses and finding remedial solutions can be fairly standardized procedures. Finding and remedying kiln and dryer production rate shortcomings require additional expertise in areas of kiln and dryer design and operation.

The scope for increased production for a given kiln is usually determined from a comparison of the kiln's actual performance, usually determined by travelling thermocouple traces and tests of ware in various stages of firing, with laboratory or pilot plant tests which generate a theoretical or design firing process. Travelling thermocouple tests are used to determine if all parts of the setting have reached a prescribed temperature uniformly by a certain time or position in a tunnel kiln to allow a faster firing schedule.

With the above information on hand, and results of modifications of other similar kilns, an experienced kiln designer can determine what modifications are necessary for a particular kiln. On the other hand, some plants have reported increasing their kiln's production with inhouse expertise - in each case the importance of travelling thermocouple tests was stressed. Use of high velocity burners throughout the kiln is being reported over and over again with claimed fuel savings of up to 25 percent.

Because of the interrelation of process phases, a change in conditions in any one part of the kiln directly or indirectly affects other parts of the kiln and the dryer. For example, an improvement in preheat firing to allow a faster schedule, would likely require improvement in cooling to accommodate the higher rate of production. A simple cooling change such as an increased volume of cooling air would increase the volume of hot air to the dryer and possibly the amount of cooling air entering the firing zone. On the other hand providing better recirculation of cooling air may only result in an increase in hot air temperature. Kiln operation dictates the quantity and quality of hot air supply to the dryer - hence the dryer must adapt. If the temperature of the hot air becomes too low, supplemented heating may become necessary at the dryer.

Any improvements to the kiln must then be carried out stepwise with the results of each step fully studied before undertaking the next step. Fuel savings and kiln conditions obtaining after the say, 4th or 5th kiln modification step cannot be accurately predicted in advance at the offset or possibly even after the first or second improvement steps. An orderly and effective kiln upgrading program requires that the program be ongoing over a period of time under a qualified engineer with management commitment to the task.

In recognition of the foregoing, a three-phased program is recommended for the study facility. First, a brief mention of some recent developments in kiln design, instrumentation and operation.

1. A microprocessor-based distributive control system designed to optimize ceramic industry processes provides total control of the process including staged burner operation, control of excess air, flue temperatures, fuel input, kiln temperatures, kiln pressures, kiln oxygen concentrations, etc. Such a system may be easy to justify economically for a new state-of-the-art kiln designed to operate on a number of products, but would be much more difficult to justify for an old kiln, say 15 or 20 years old.

   Electronic automation systems offer the following potential advantages:
    - possibility of using highly complex programs,
    - ease in modifying existing sequences,
    - automatic detection of faults or failures,
    - centralization of control commands,
    - logging of selected operational data.

2. Kilns constructed with modular steel shells lined with ceramic fiber refractory and insulation in lieu of face brick, solid refractories, and insulating brick.

3. Introduction of molecular oxygen into the oxidation-preheat zone to speed oxidation reactions and thus shorten the length of kiln required for this process to take place - termed oxygen lancing.

4. A telemetering system which reads temperatures throughout the kiln car setting at up to eight locations and monitors and records actual temperature profiles that the products are subjected to by using FM radio frequencies with an eight channel transmitter mounted under the kiln car.

A tunnel kiln, once adjusted to a particular product, is quite stable in operation since conditions do not change appreciably with time. Over time, air flows, temperatures and other operating variables can be fine tuned for minimum fuel use, minimum product rejects, optimum product quality, etc. Where variations do occur and are of such frequent nature that it is impractical to provide constant manual adjustments, margins of safety are provided, such as an overly high temperature or oxygen concentration. When the kiln is used for production of several products, a high degree of fine tuning of the process becomes impractical and such safety margins or compromises tend to increase. This situation largely prevails in the study kiln and dryer.

The cost and limited track record of electronic automation systems detracts from their application to old kilns and dryers, such as the facility being studied here. A more apt and practical approach would be to define existing operating conditions and problems and systematically implement improvements to increase product rates, decrease energy losses, decrease the percentage of unmarketable product rejects and thus reduce fuel use. These steps, in any event, would need to be carried out for purposes of implementing any centralized automation system.

In the proposed three-phased program for fuel use savings, Phase I involves improvements to the kiln and dryer through measures which fall largely into process adjustment, better maintenance and operating procedures, insulation of the roof of the firing zone, insulation of kiln-to-dryer hot air supply duct and dryer fans and ducts, connection of dryer exhaust to predryer and replacement of firing zone burners with high velocity burners.

The completion of Phase I work will change process conditions throughout the kiln dramatically and, to a lesser extent, in the dryer. Before proceeding to modify the kiln for further fuel use reductions through increased production rate, further heat loss reductions, and possibly heat recovery a study program is necessary to define new process conditions and to obtain criteria for evaluation and design of feasible alternatives. Such a study program comprises Phase II of the overall fuel use reduction program.

Phase III predictably involves technical and economic evaluation of potential alternatives for further fuel use reduction and their design and implementation.

Obviously, further treatment of only elements of Phase I falls within the scope of this report. Although considerable scope for further fuel use reductions will remain after implementation of measures recommended in Phase I, their feasibility must be evaluated on the basis of process conditions prevailing at that time. Phase II describes a subsequent study program for further action as Phase III. Elements of Phase III are forecast, it is felt with reasonable accuracy, based on the kind of kiln and dryer modifications that have been reported elsewhere.

6.2 PHASE I - Process and Equipment Adjustments, Insulation, Replacement of Firing Zone Burners and Recovered Heat Supply to Predryer

1. Improve airtightness of kiln and dryer tunnels.
   a. Seal all openings around doors and cracks in brickwork.
   b. Close all unnecessary openings in tunnels.
   c. Rebuild or replace refractory radiation shields on cars to improve their effectiveness as convection seals.
   d. Check effectiveness of sand convection seals and take appropriate countermeasures such as selecting a more suitable sand grain size or mix, using more sand, and more operator attention to seals.
   e. Install car end seals of 1/2" or 1" ceramic fiber rope covered with alloy mesh to protect against wear.

    f. Check settings of dampers in preheat and cooling zones. Some dampers in the cooling zone, through either being open or faulty, may be the cause of high leakage of hot air out of the tunnel noticed on the tunnel exit side of the car cooling air supply fan.

2. Balance outputs of dryer hot air supply and exhaust fans. Currently, the air exhaust rate is roughly double the air supply rate (mass basis) resulting in high negative pressures in the dryer, high air infiltration, and high stack heat loss.

3. Adjust kiln exhaust fan for minimum volume and minimum temperature of exhaust gases consistent with product quality and maintenance of existing kiln schedules.

4. Repair natural gas leaks in piping and in unused oil valves on firing zone burners.

5. Reactivate natural gas meter for tunnel kiln and keep fuel consumption records for each shift.

6. Adjust high velocity burners for firing at near stoichiometric fuel-air ratio to the extent of maintaining 150 percent excess air in the preheat zone and about 2 percent oxygen in flue gases leaving the firing zone. Firing at or near soichiometric ratio will also improve mixing effect of the burners.

7. Check accuracy of thermocouple temperature readings and replace deteriorated thermocouples. Chromel/alumel thermocouples are less costly than the platinum/rhodium/platinum that are in use and could be substituted.

8. Firing zone burners may be firing fuel rich because the gas pressure used is considerably in excess of that recommended by the burner manufacturer. This should be checked after the crown high velocity burners are set for firing near stoichiometric ratio.

9. Insulate kiln-to-dryer hot air duct and dryer fans and ducts. Because the dryer supply fan cannot accept an increase in temperature in excess of about 600°F (316°C) the volume of hot air will have to be increased in order to convey the energy saved (by insulation) to the dryer. Additional heat in the dryer exhaust can be utilized in the predryer.

10. Connect dryer exhaust to predryer air supply and provide a predryer exhaust fan. Ideally, for purposes of better control, it would be advantageous to connect the fresh hot air supply to the predryer, whereby fresh hot air could be supplied to the dryer at several points as described in Section 5.3.1, but the distance over which the fresh hot air would have to be supplied to the predryer detracts from this alternative.

11. Insulate the roof of the firing zone with 4" thich layer of mineral wool.

12. Replace open-type nozzle mix (North American No. 225-2) firing zone burners with high velocity burners (such as North American No. 4442-2).

The technical justifications for installation of the high velocity burners are:

- more thorough penetration and more uniform heat up of the setting making faster schedules possible.
- stable operation on stoichiometric fuel-air ratio.

- possible operation at up to 30 percent excess fuel which would allow more hot cooling air to be admitted to the firing zone by operating some burners in the latter part of the zone fuel rich while operating others on or near stoichiometric ratio.
- burners have integral metering orifices for air and gas which would allow for accurate checks and control of fuel-air ratio.
- existing burners are in poor condition and in need of replacement with new burners.

The high velocity burner installation will also measurably increase the airtightness of firing zone and eliminate openings which are presently the root of high radiation losses. Experience elsewhere indicates that because the burners are more efficient, a lesser number will be needed to accomplish the process of quickly heating up the ware in all parts of the setting to maximum temperature enabling the soak period to be achieved over a lesser length of kiln. This means that the oxidation-preheat zone and/or cooling zone can be made longer. In this case it should be the oxidation-preheat zone as it is the bottleneck to increasing the production schedule for medium duty firebrick. However, once a faster schedule is possible in the oxidation-preheat zone it will also be imposed on the firing zone and cooling zone. Therefore, it may be then necessary to return some burners to the firing zone and improve the efficiency of cooling in the cooling zone. The obvious way of increasing cooling is to redesign and rebuild a quick cooling section in the location of the original one that was dismantled. There are of course additional ways of improving cooling further downstream in the cooling zone.

To achieve or make possible a faster schedule in the oxidation-preheat zone the period of time (or kiln length) that the ware is in the temperature range of high oxidation rate 1500° to 1800°F (816° to 982°C) must be effectively lengthened by raising the temperature of the ware into the temperature range earlier or by extending the time period after it enters it. The scenario described in the preceeding paragraph would lengthen the time period. The time period could also be effectively lengthened by providing forced circulation fans in the previous recirculating section from which fans have been removed. If kiln schedules are to be increased the oxidation-preheat process must be speeded up. Since new and more fuel-efficient burners are needed in the firing zone it is best to wait and see how the oxidation-preheat zone is affected before proceeding with the recirculation alternative.

6.3 PHASE II - Process and Problem Definition and Development of Criteria for Further Fuel Use Reduction Steps

1. Design and implement a study program to define new process conditions resulting from Phase I work, equipment performance, and impediments remaining to faster kiln schedules - initially to obtain finer tuning of the kiln and dryer and then to establish criteria for design of modifications to the kiln and dryer for increased production schedules, further reduction of heat losses, and possibly heat recovery for further fuel savings. This report already accomplishes much of the above and should serve as the springboard for the above program - which would essentially be a continuation of this work. Information generated by the study program should include the following for each major product:
    a. Oxygen and carbon dioxide concentrations in the flue gases leaving the firing zone and in the flue gases being exhausted.
    b. Oxygen concentration at the firing zone product exit end and in the hot air from the cooling zone leaving for the dryer.
    c. Oxygen profiles for preheat and firing zones.
    d. Kiln and dryer pressure profiles.
    e. Kiln and dryer temperature profiles for different parts of the setting (e.g. top, bottom, sides, inside of pack) all measured simultaneously by means of travelling thermocouples.

f. Dryer atmosphere humidity profiles.

g. Fuel-air ratio records for burners.

h. Product recovery records (i.e. percentage of product that is saleable).

i. Natural gas consumption records.

j. Temperatures of products entering and leaving kiln and dryer.

k. Kiln and dryer surface temperatures at a number of selected critical points for determination of heat losses.

l. Heat and air balances for kiln. Heat, air and moisture balances for dryer.

m. An assessment of the results of the Phase I high velocity burner installation in the firing zone.

Instruments necessary for the Phase II work include the following:

- Portable oxygen, carbon dioxide and carbon monoxide analyzer(s).
- Pitot-tube (48" long).
- Inclined tube manometer or Dwyer pressure gauges 0 to 0.25" w.c., 0 to 0.50" W.C. and 0 to 2" w.c.
- 1/4" nom. dia. alloy pipe probe for taking kiln and dryer pressure readings.
- Dial thermometers (2 or 3 with different ranges).
- Wet and dry bulb thermometers.
- Infra-red pyrometer would definitely be a valuable tool for surface temperature measurements and measurement of temperature of ware in process.

Total cost of the above instruments would be about $7,000, of which $4,000 is for the portable analyzer and $1,200 for the infra-red pyrometer.

6.4 PHASE III - Fuel Use Reduction Through Increase in Production Rate, Additional Heat Loss Prevention and Possible Heat Recovery

This phase of work, predicated on Phase II studies, will include technical and economic evaluations of further (to those in Phase I) measures to reduce fuel use, design of process and equipment modifications and their implementation.

Based on reported upgrades of kilns and dryers elsewhere and results of this study prediction of the following scenario is felt to be fairly accurate.

Although oxidation-preheat process will benefit measurably from the installation of high velocity burners in the firing zone through lengthening of the period in which temperature conditions are optimum for oxidation, some recirculation will still be necessary both for increasing schedules and decreasing stack heat losses through reduction of flue gas volume and temperature. With faster schedules thus made possible in the preheat zone, and faster schedules already ascertained by installation of high velocity burners in the firing zone,the bottleneck to faster kiln schedules will shift to the cooling zone. The changes then necessary in the cooling zone will be:

- a quick cooling system for cooling ware from maximum firing temperature to 1200°F (649°C) such as illustrated in Figure 12.
- a fast cooling section at the kiln exit for cooling ware below 600°F (316°C). This can be accomplished with use of the existing cooling air supply fan.
- a system for control of cooling rate between 1200°F (649°C) and 600° (316°C) (in which range the ware must be cooled slowly for purposes of annealing) with two hot air offtakes as illustrated in Figure 13. It works as follows: if slower cooling in the annealing section is required more air is pulled off at the cold end of the section than at the hot end; the reverse being true for faster cooling.

- a door at the kiln exit to allow the cooling air supply fan to build up positive pressure and air flow in the cooling section.

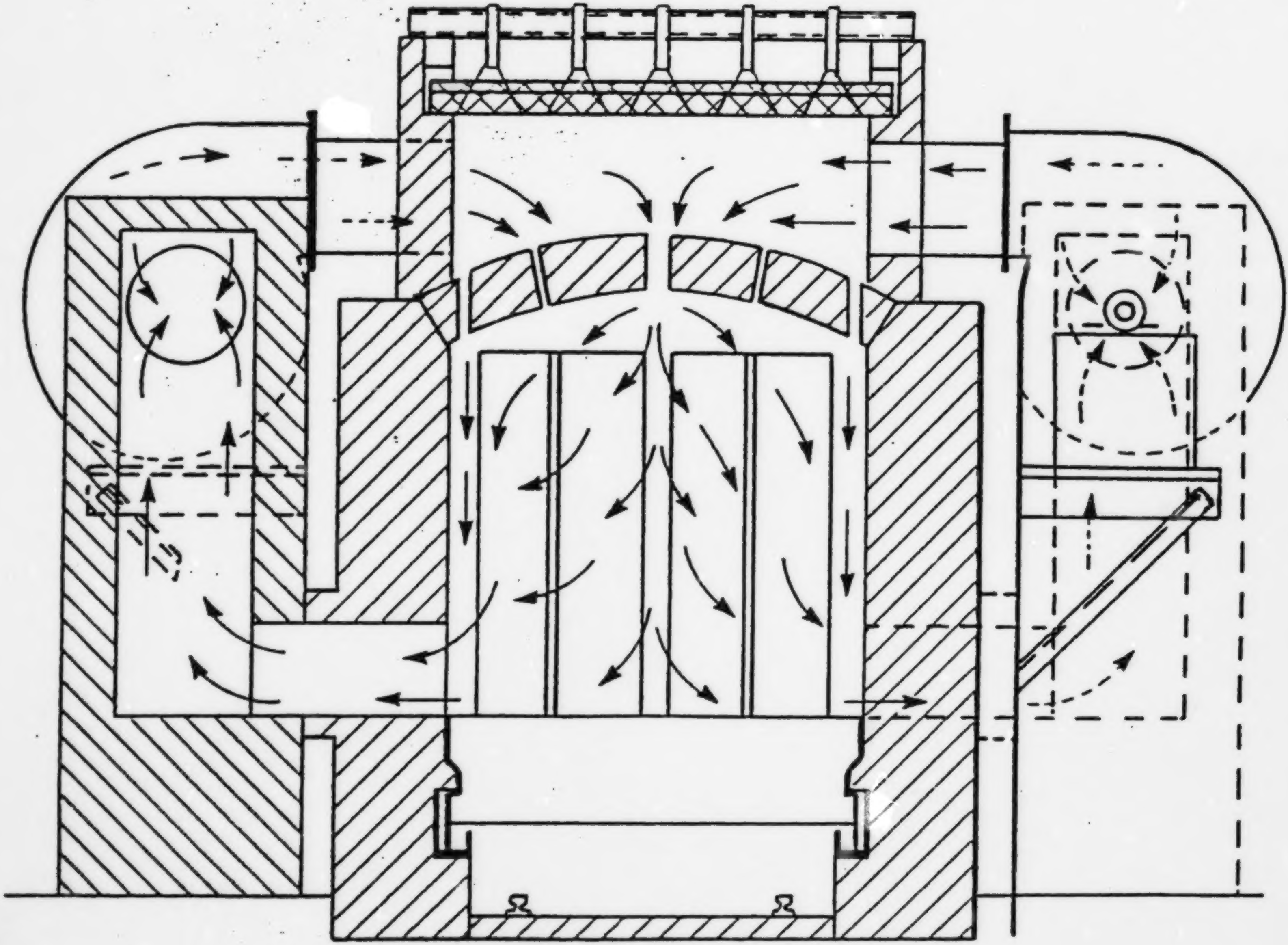


FIGURE 12 - ILLUSTRATION OF QUICK COOLING SYSTEM
(After Fay, G.F., "Quenching Zone Scheme Allows
Faster Push Rates", Brick and Clay Record, Feb. 1985)

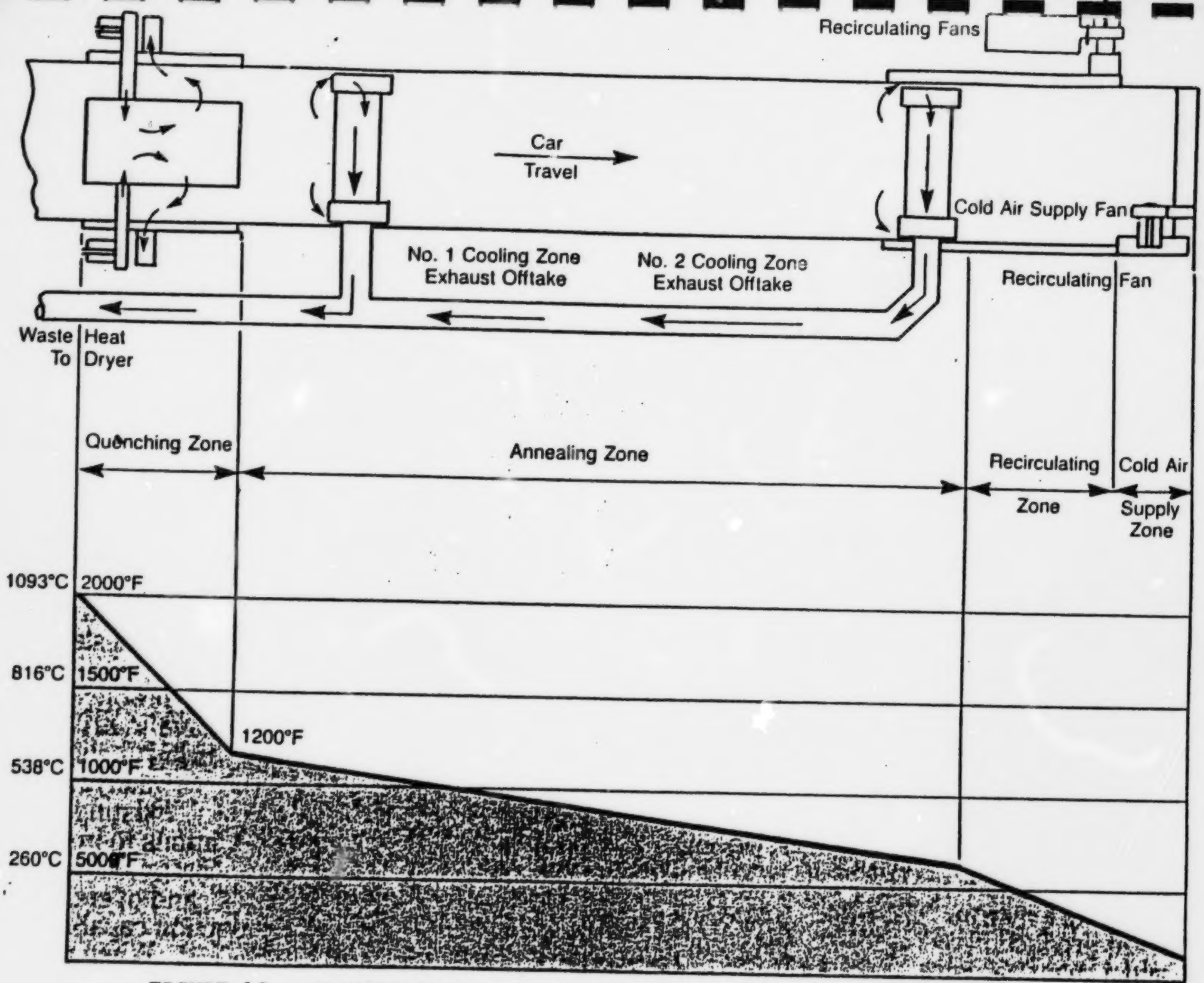


FIGURE 13 - ILLUSTRATION OF A SYSTEM FOR IMPROVED CONTROL OF COOLING RATE (After Fay, G.F., "Quenching Zone Scheme Allows Faster Push Rates", Brick and Clay Record, Feb. 1985)

7.0 ECONOMIC EVALUATIONS (PHASE 1)

Economic evaluations in this section are for the Phase I work described in Section 6.2. Items 1 to 8 are in the category of good maintenance and operational practices which normally should be carried out; hence they are not treated as capital outlays. Items 9, 10, 11, 12 and 13 require capital expenditures for which economic evaluations follow. Calculations and analysis are found in Appendix D. Results of economic evaluations are summarized in Table IV.

Because energy saved by insulating the kiln-to-dryer duct and the dryer fans and ducts (item 9) cannot be utilized unless the dryer exhaust is connected to the predryer air supply (item 10), items 9 and 10 must be evaluated as one energy conservation measure. There are then three capital expenditure measures proposed for Phase I which will be referred to as:

- connection of dryer exhaust to predryer
- replacement of firing zone burners
- insulation of firing zone roof

None of the above measures would result in an increase in maintenance or operating costs.

7.1 CONNECTION OF DRYER EXHAUST TO PREDRYER

Work in this energy conservation measure involves insulation of the kiln-to-dryer duct, insulation of dryer fans and ducts and connection of dryer exhaust to predryer for which cost estimates follow.

1. Insulation of Kiln-to-Dryer Hot Air Duct

   This duct is 36" (0.914 m) diameter by 300 feet (91.44 m) long. Economic thickness of fiberglass blanket insulation is 6 inches (152 mm). Estimated capital cost is $37,700. Energy savings amount to 26,340,000 Btu/day (27,790 MJ/day).

2. Insulation of Dryer Fans and Ducts

Surface heat loss is about 5,544,000 Btu/day (5,849 MJ/day) from 660 ft.^{2} (61.3 m^2) of bare steel surfaces. An insulation supplier's analysis indicates the following economic thicknesses:

Supply fan:	: 6" (152 mm)
Recirculating fan No. 4, No. 3, No. 2 and No. 1	: 4" (101 mm)
Exhaust fan	: 3" (76 mm)

Using 4" (101 mm) thick aluminum jacketed insulation throughout, the capital cost, based on a unit cost of \$7.98/ft.^{2} is \$5,270. Energy savings would be about 5,455,000 Btu/day (5,695 MJ/day).

Heat loss from the dryer sides and roof is estimated at 6,115,000 Btu/day (6,452 MJ/day). Insulation of the roof, where the major heat loss occurs, can be very economically done using 4" (101 mm) thick fiberglass batt insulation.

Drawings of the dryer are found in Appendix F.

3. Dryer-to-Predryer Hot Air Duct

Work in this category involves connection of the dryer exhaust to the predryer air supply by means of a 100 foot long (30.48 m) 26" (660 mm) diameter 10 gauge steel duct insulated with 4" (101 mm) thick aluminum jacketed fiberglass insulation. The existing brick stack would have to be removed, because it is located directly over the vertical fan discharger, and replaced with a steel stack with a dampered plenum below it for directing a portion or all of the exhaust to atmosphere. Capital cost is broken down as follows:

Steel duct	\$12,000
Insulation	9,300
Removal of existing chimney	1,400
Total capital cost	\$21,700

4. Total Capital Cost and Simple Payback Period

The total capital cost for connection of the dryer to predryer (estimated in 1, 2 and 3 and rounded out) is $64,700. The energy thus made available for the predryer is of the order of 31,800,000 Btu/day (33,546 MJ/day). With a unit energy cost of $4.20/1,000,000 Btu the simple payback period is,

$$\frac{\$64,700}{31.80 \times \$4.20 \times 365} = 1.26 \text{ years}$$

An added benefit, apart from eliminating the use of natural gas in the predryer, would be improved predryer performance because of the increased volume of supply air made available. One of the reasons for poor performance of the predryer appears to be the low volume of supply air and poor circulation.

The cost of a predryer exhaust fan, about $3,800 installed, was not included in the above estimate because it is needed whether the dryer is or is not connected to the predryer.

7.2 FIRING ZONE BURNER REPLACEMENT

This energy conservation measure involves the replacement of 38 existing open-type nozzle mix burners with 38 high velocity burners and sealing of the burner wickets by reconstruction with common brick and insulating refractory or ceramic fiber refractory. The cost of each high velocity burner (North American No. 4442-2, -3, or -4), is $620, exclusive of taxes. Cost of 38 burners alone would be $28,000. Installation would add another $10,000, for a total capital cost of $38,000.

Benefits of fuel savings, faster schedules, higher product recovery and improved product quality are difficult to ascertain. There is also the additional factor that the existing burners are deteriorated and in need of replacement such that a portion of the capital expenditure should properly be allocated to maintenance and only the additional cost for high velocity burners is allocated to capital expenditure. Using the following experience in various papers and reports,

- shutting down burners on one third the length of the firing zone reduced fuel consumption by 15 percent. Any gain in preheat zone length would improve heat recovery and speed oxidation reactions,
- a 3 percent recovery improvement or a 20 percent faster schedule would give a payback period of between 1 or 2 years. If both were realized the payback time should be about one year,

- fuel efficiency increases of 10 to 25 percent are reported for high velocity burners,

a fuel reduction of 5 percent is assumed. On the basis of an average monthly billing of about \$55,000 for natural gas the payback period is:

$$\frac{\$38,000}{\$55,000 \times 12 \times 0.05} = 1.15 \text{ years}$$

7.3 INSULATION OF KILN FIRING ZONE ROOF

Insulation remaining on the kiln roof is equivalent to about 2" (51 mm) of diatomaceous earth. Calculations (Appendix D) of resulting increases in refractory and insulating firebrick working temperatures show that a 4" (102mm) layer of mineral wool insulation can be safely applied. A 6-inch (152 mm) layer of mineral wool would result in temperature limits for insulating firebrick and mineral wool to be exceeded. Since even with 4" (102 mm) the mineral wool would be subjected to a contact temperature slightly in excess of its limit, a one-half inch thickness of ceramic fiber to overlay the existing insulation would be a worthwhile precaution.

TABLE IV - SUMMARY OF ECONOMIC EVALUATION

ENERGY CONSERVATION MEASURE	ENERGY SAVING Btu/day	ENERGY SAVING (MJ/day)	CAPITAL COST, $(2)	SIMPLE PAYBACK PERIOD, Yr.
1. Connection of dryer exhaust to predryer comprising: - insulation of kiln-to-dryer hot air duct (1) - insulation of dryer fans and ducts (1) - new 26" dia. dryer-to-predryer duct - new predryer exhaust fan	31,800,000	(33,546)	64,700	1.26
2. Replacement of kiln firing zone burners with high velocity burners	21,526,000	(22,710)	38,000	1.15
3. Insulation of kiln firing zone roof with 4 inches (102 mm) of mineral wool	4,610,000	(4,863)	3,500	0.41

(1) These measures conserve heat for ultimate use in the predryer (i.e. 31,800,000 Btu/day).

(2) In 1985 dollars.

Capital cost of the mineral wool insulation is $3,500. Energy saving is 4,610,000 Btu/day (4,863 MJ/day) giving a simple payback period of 0.41 year.

With the above measure firing zone roof heat loss is reduced from about 8,946,000 Btu/day (9,439 MJ/day) to 4,336,000 Btu/day (4,575 MJ/day). Further heat loss reductions are possible by lining the ceiling of the firing zone with ceramic fiber refractory. However, it involves the risk of deterioration by possible alkaline atmospheres and damage by wrecks (i.e. toppling of the setting) and is much more costly than the exterior insulation proposed.

7.4 TOTAL IMPLEMENTATION COST

For purposes of this study, project costs are required for implemention of Phase I works described in this study and monitoring performance of the upgraded kiln and dryer and to a lesser extent the predryer in the following phases:

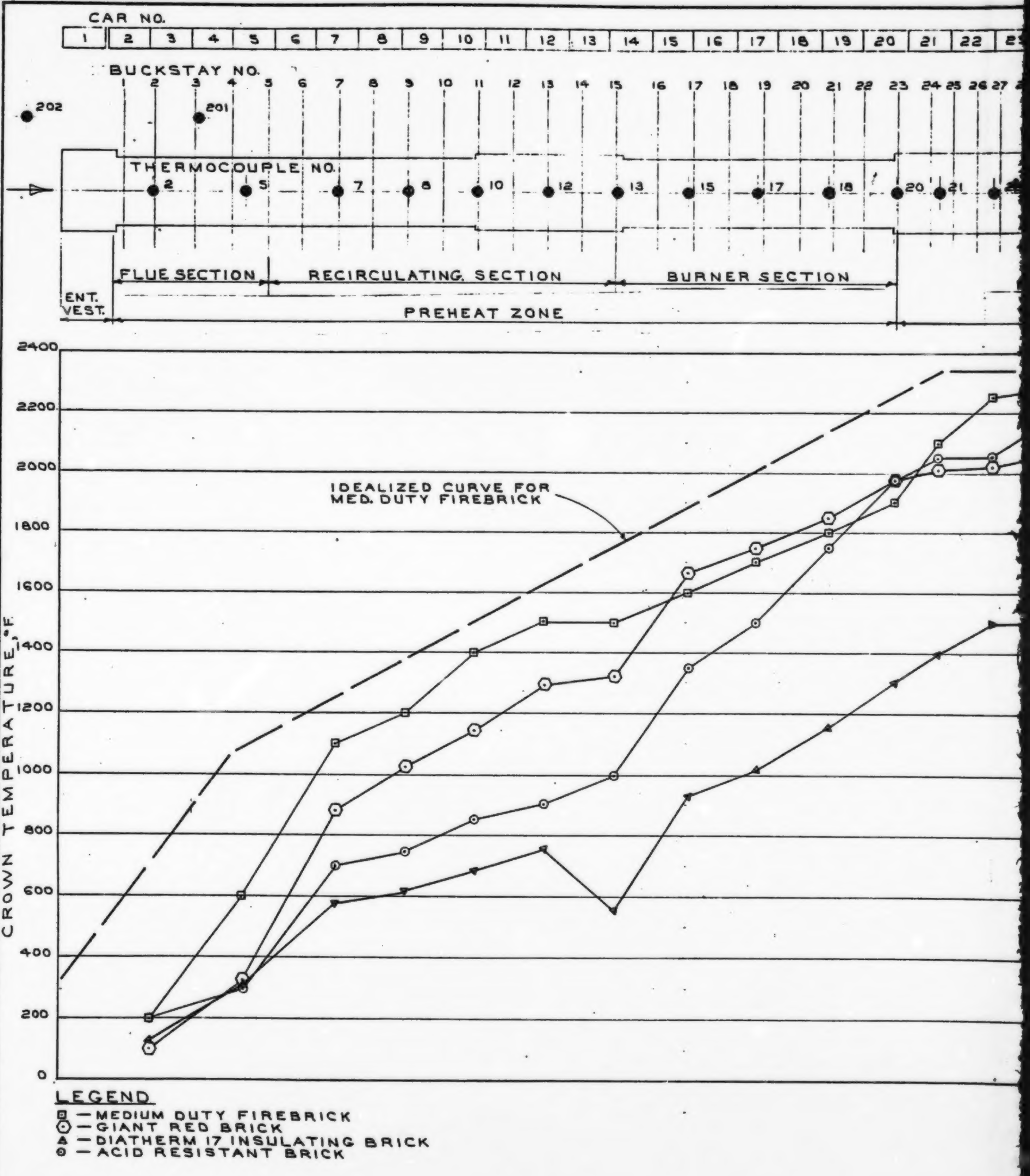
Phase IP:	This pre-engineering survey or study for which costs are already known.
Phase IIP:	Detailed engineering plan for modifications and costs for the following Phases IIIP and IVP.
Phase IIIP:	Retrofit of equipment and commissioning and acceptance by the owner of the upgraded facility.
Phase IVP:	9-month monitoring and maintenance of the upgraded facility.

The estimated costs for each of the energy conservation measures are listed below.

Energy Conservation Measure	Estimated Cost, $ (1985)		
	Phase IIP	Phase IIIP	Phase IVP
Connection of dryer exhaust to predryer	7,200	64,700	5,000
Firing zone burner replacement	4,000	39,000	4,500
Firing zone roof insulation	800	4,000	1,600

Phase IIIP costs include capital costs, costs of construction engineering services, and commissioning of equipment. Phase IVP includes costs for preparation of a report at the end of the monitoring period. The 9-month monitoring program referred to in this section as Phase IVP can, with little additional effort, be carried out coincidentally with the work described as Phase II in Section 6.3.

APPENDIX E - CHARTS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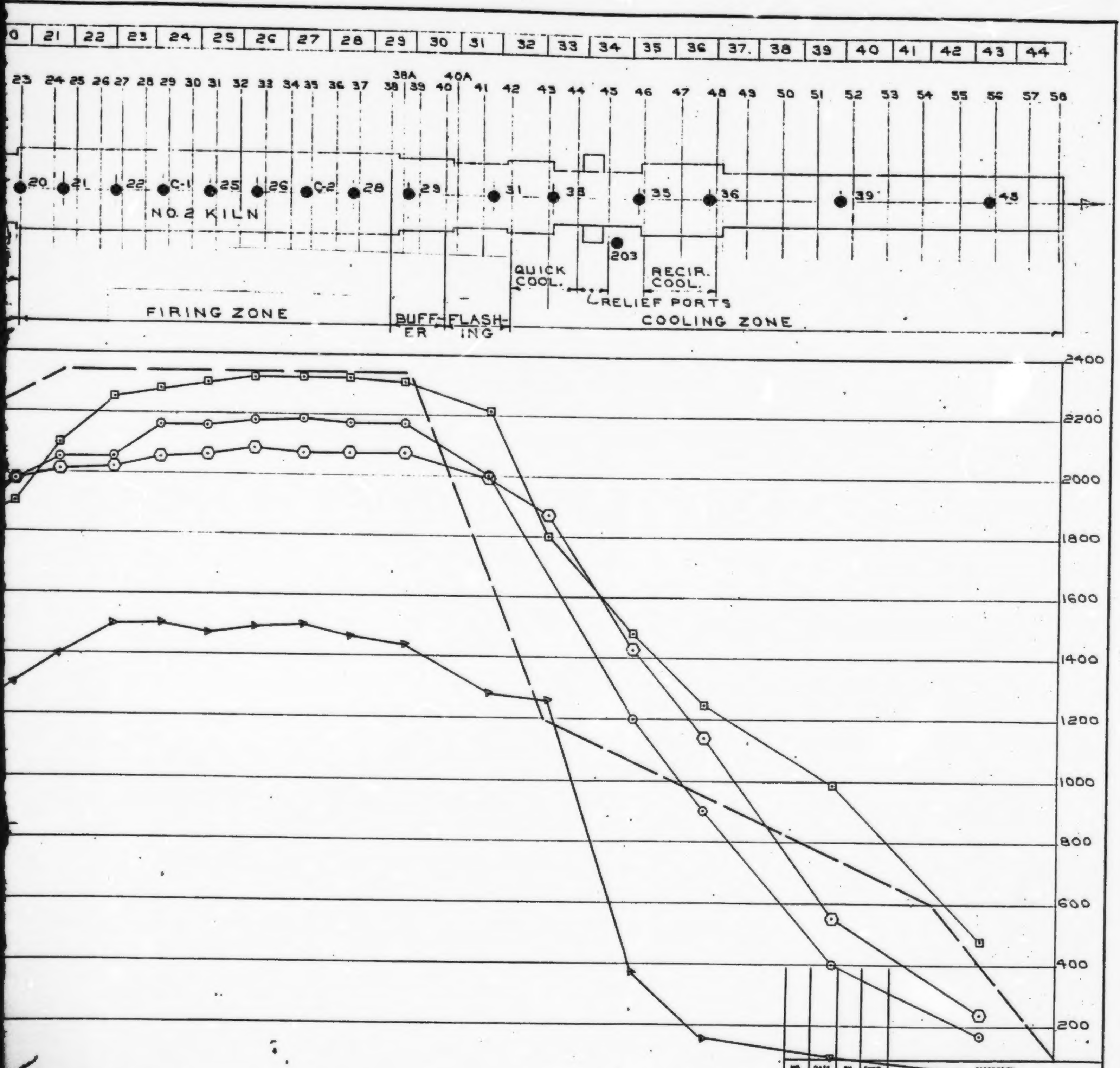
BUCKSTAY NO.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
202
201
THERMOCOUPLE NO.
2 5 7 8 10 12 13 15 17 18 20 21
FLUE SECTION
RECIRCULATING SECTION
BURNER SECTION
ENT. VEST.
PREHEAT ZONE
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
CROWN TEMPERATURE, °F
IDEALIZED CURVE FOR MED. DUTY FIREBRICK
LEGEND
⊡ — MEDIUM DUTY FIREBRICK
⬡ — GIANT RED BRICK
▲ — DIATHERM 17 INSULATING BRICK
⊙ — ACID RESISTANT BRICK



NO.	DATE	BY	CHKD.	DESCRIPTION

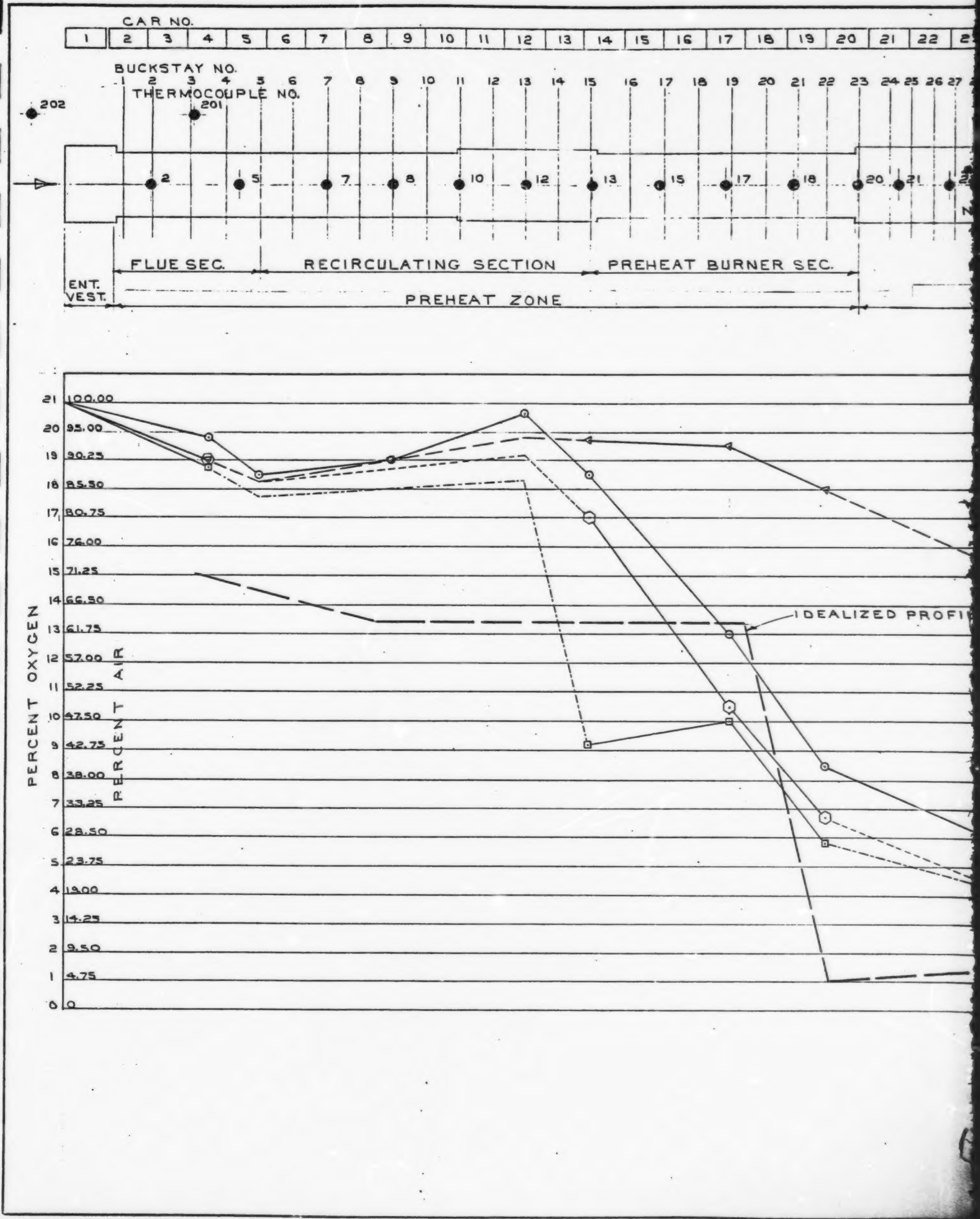
REVISIONS

KENT ENGINEERING LTD.
VANCOUVER B.C. CANADA

CHART IE

TUNNEL KILN CROWN PRESCRIBED TEMRERA-ATURE PROFILES

SCALE	CHECKED BY	
DESIGN BY	APPROVED BY	
DRAWN BY	DATE	DRAWING NUMBER / REV


CAR NO.
1
2
3
4
5
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16
17
18
19
20
21
22
BUCKSTAY NO.
1
2
3
4
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6
7
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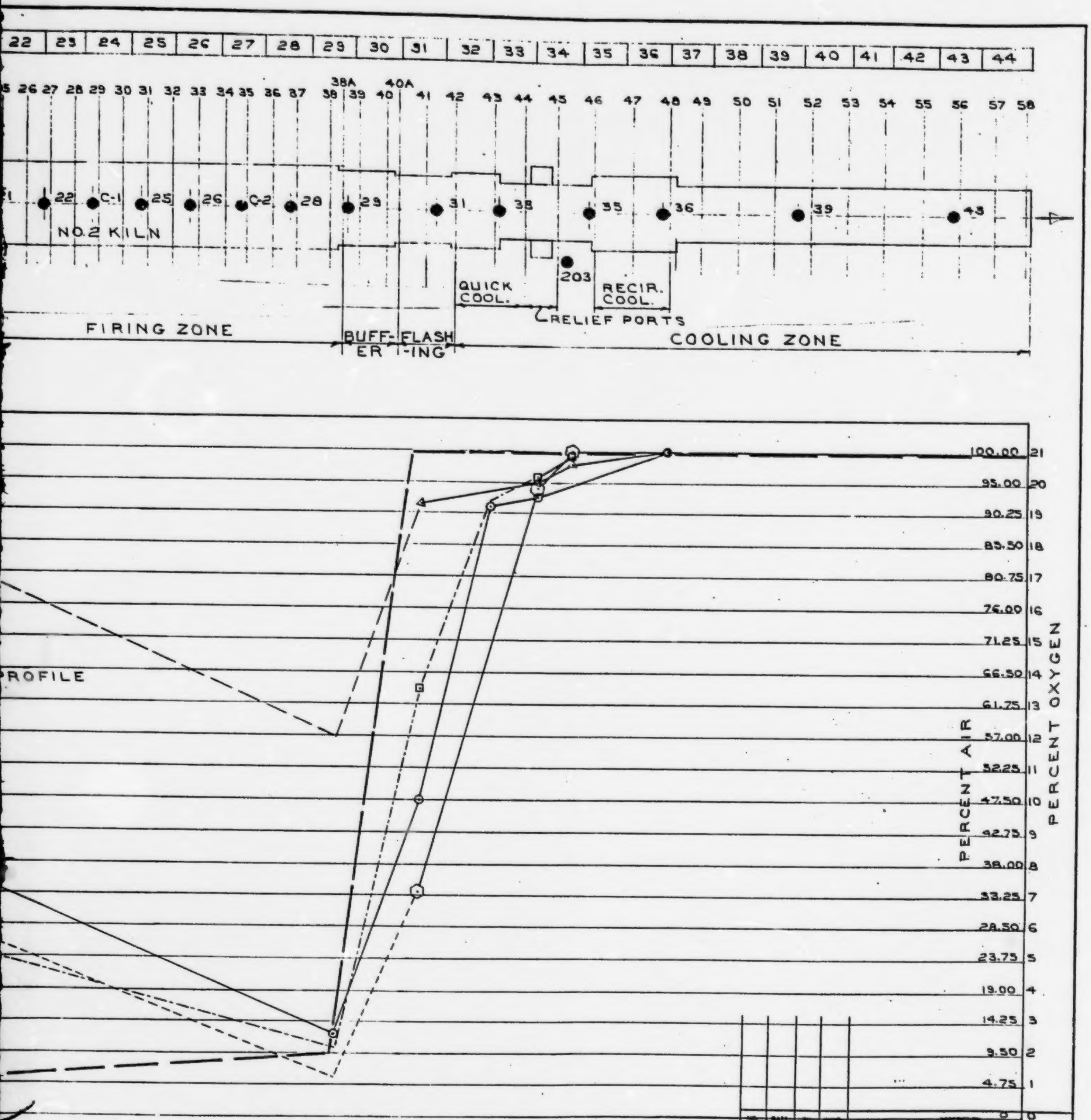
15
16
17
18
19
20
21
22
23
24
25
26
27
THERMOCOUPLE NO.
202
201
2
5
7
8
10
12
13
15
17
18
20
21
FLUE SEC.
RECIRCULATING SECTION
PREHEAT BURNER SEC.
ENT. VEST.
PREHEAT ZONE
PERCENT OXYGEN
PERCENT AIR
21 100.00
20 95.00
19 90.25
18 85.50
17 80.75
16 76.00
15 71.25
14 66.50
13 61.75
12 57.00
11 52.25
10 47.50
9 42.75
8 38.00
7 33.25
6 28.50
5 23.75
4 19.00
3 14.25
2 9.50
1 4.75
0 0
IDEALIZED PROFI



LEGEND

⊡ —MEDIUM DUTY FIREBRICK
⬡ —GIANT RED BRICK
△ —DIATHERM 17 INSULATING BRICK
⊙ —ACID RESISTANT BRICK

DOTTED LINES DENOTE PREDICTED TRENDS OR PATTERNS OF PORTIONS OF CURVES

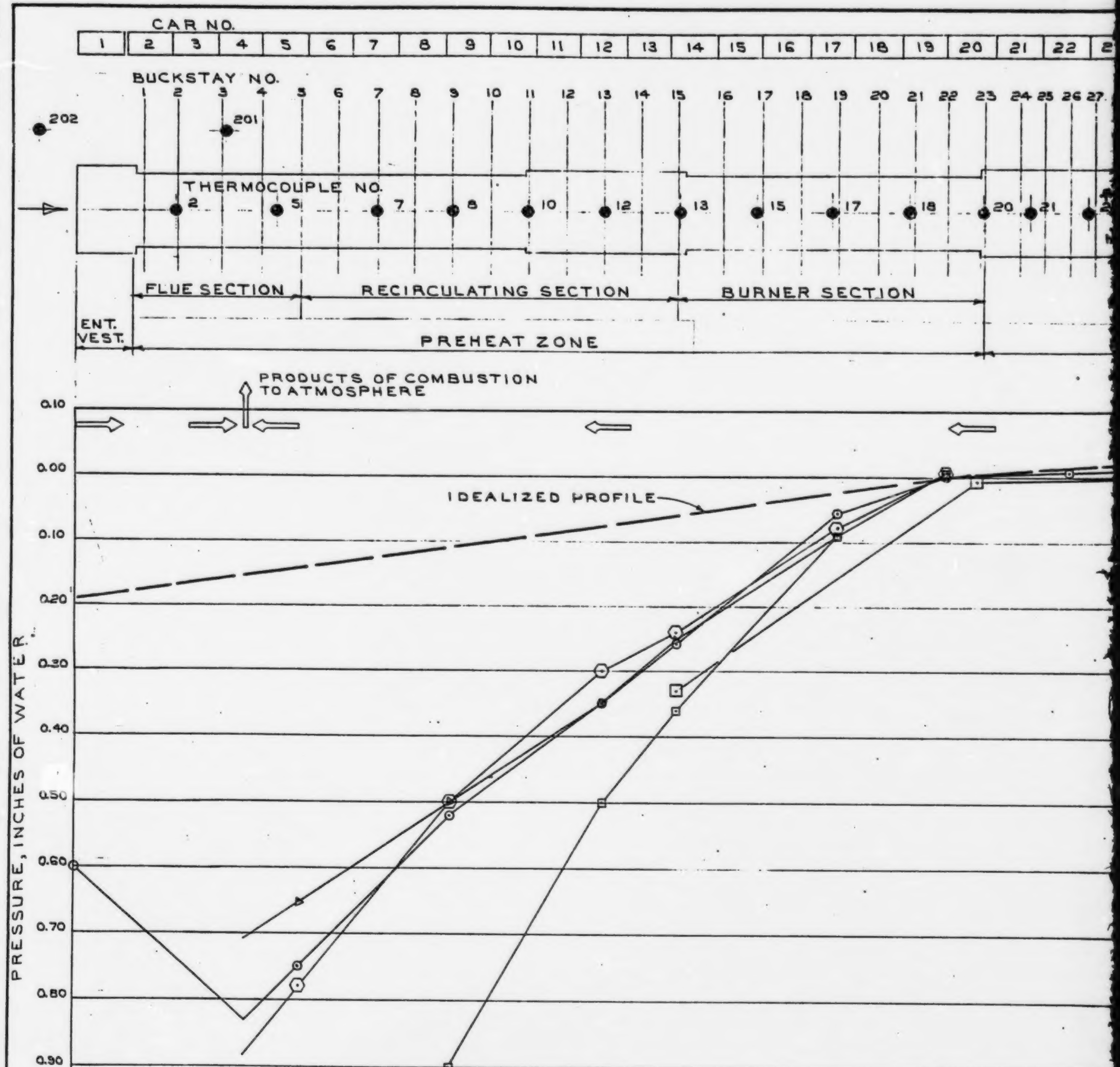
REVISIONS

KENT ENGINEERING LTD.
VANCOUVER B.C. CANADA

CHART IIE

TUNNEL KILN ATMOSPHERE OXYGEN CONCENTRATION PROFILES

SCALE	CHECKED BY	
DESIGN BY	APPROVED BY	
DRAWN BY	DATE	DRAWING NUMBER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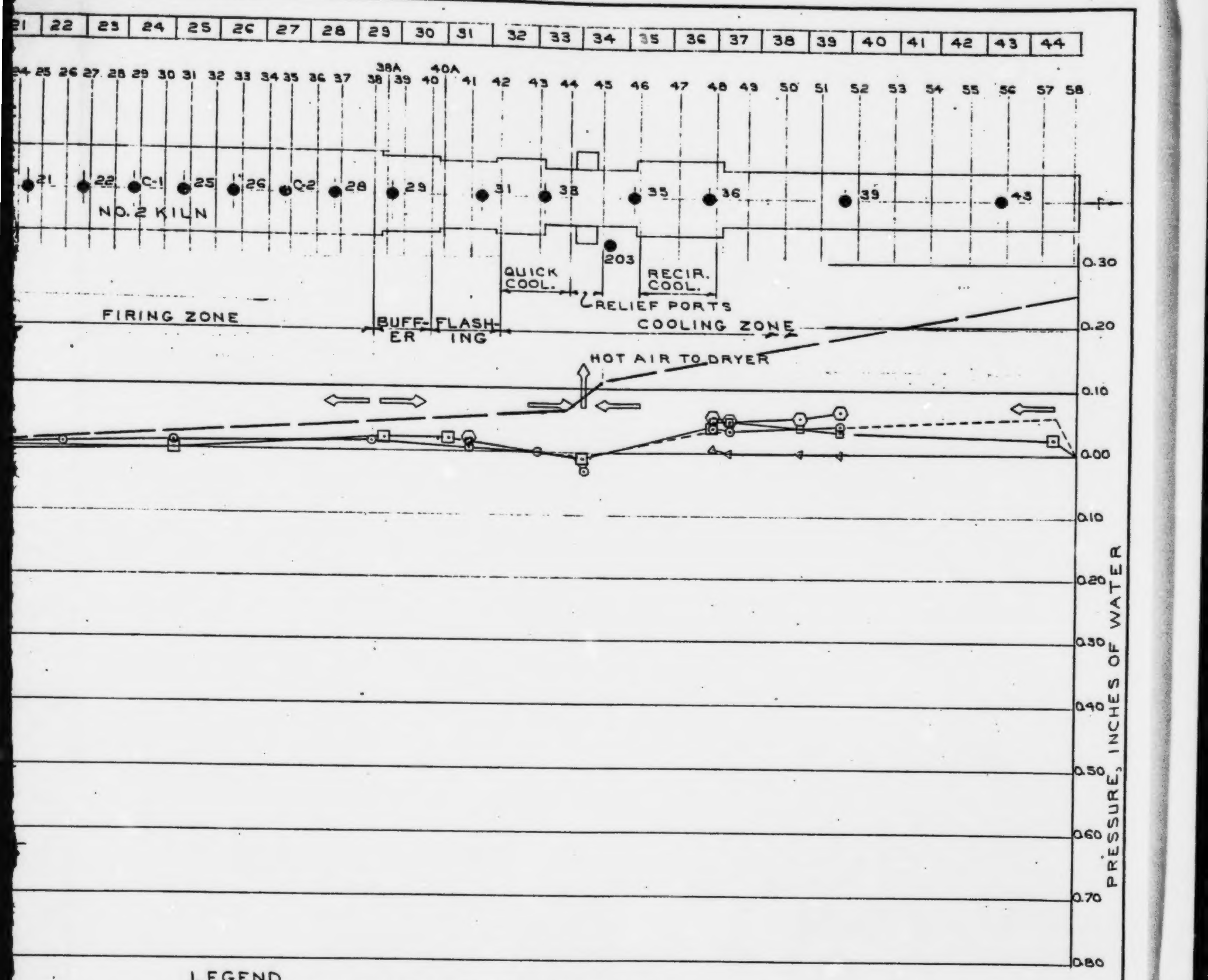
BUCKSTAY NO.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
202
201
THERMOCOUPLE NO.
2 5 7 8 10 12 13 15 17 18 20 21
FLUE SECTION
RECIRCULATING SECTION
BURNER SECTION
ENT. VEST.
PREHEAT ZONE
PRODUCTS OF COMBUSTION TO ATMOSPHERE
IDEALIZED PROFILE
PRESSURE, INCHES OF WATER
0.10
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30



LEGEND
⊡ – MEDIUM DUTY FIREBRICK ⊡ (DATA FROM SECOND TEST)
⊙ – GIANT RED BRICK
△ – DIATHERM 17 INSULATING BRICK
⊙ – ACID RESISTANT BRICK
----- EXTRAPOLATED CURVE FOR ACID BRICK
⇨ FLOW DIRECTION OF GASES IN KILN NO. 2

NO.	DATE	BY	CHKD	DESCRIPTION

REVISIONS

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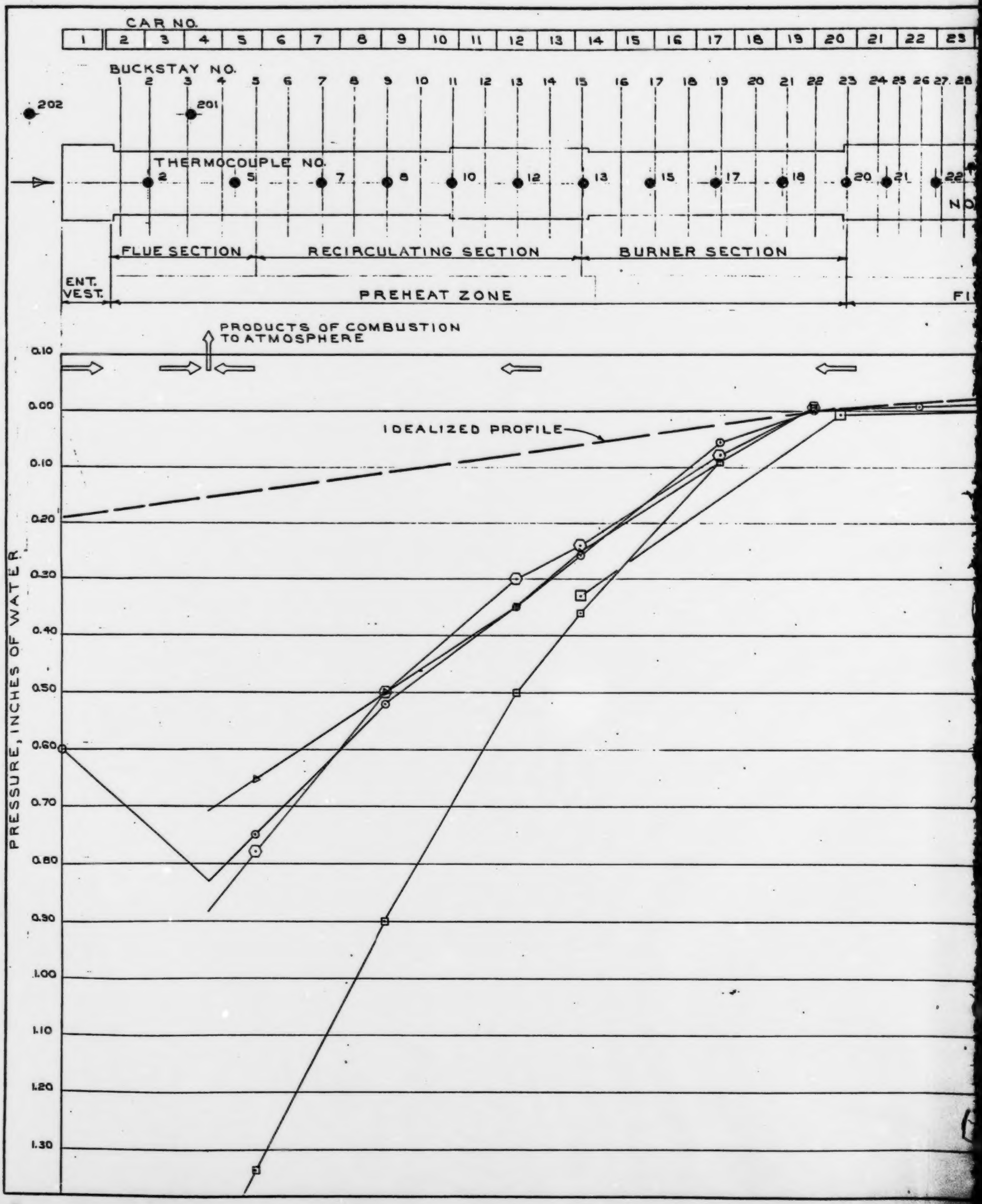
VANCOUVER B.C. CANADA

CHART IIIE

TUNNEL
KILN PRESSURE
PROFILES

SCALE
CHECKED BY
DESIGN BY
APPROVED BY
DRAWN BY
DATE
DRAWING NUMBER
REV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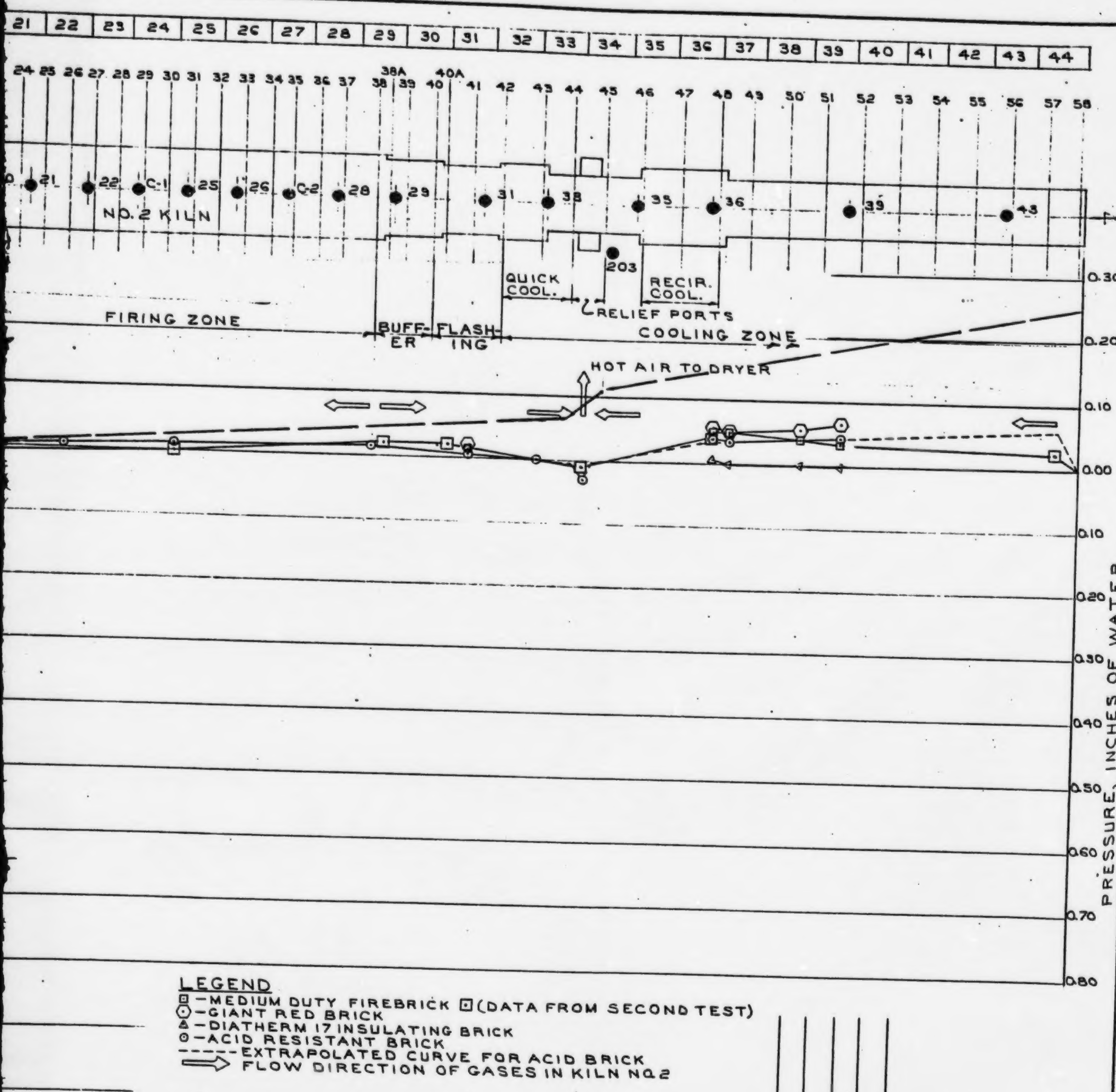
BUCKSTAY NO.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
202
201
THERMOCOUPLE NO.
2 5 7 8 10 12 13 15 17 18 20 21 22
NO
FLUE SECTION
RECIRCULATING SECTION
BURNER SECTION
ENT. VEST.
PREHEAT ZONE
FI
PRODUCTS OF COMBUSTION TO ATMOSPHERE
IDEALIZED PROFILE
PRESSURE, INCHES OF WATER
0.10
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30



NO.	DATE	BY	CHKD	DESCRIPTION

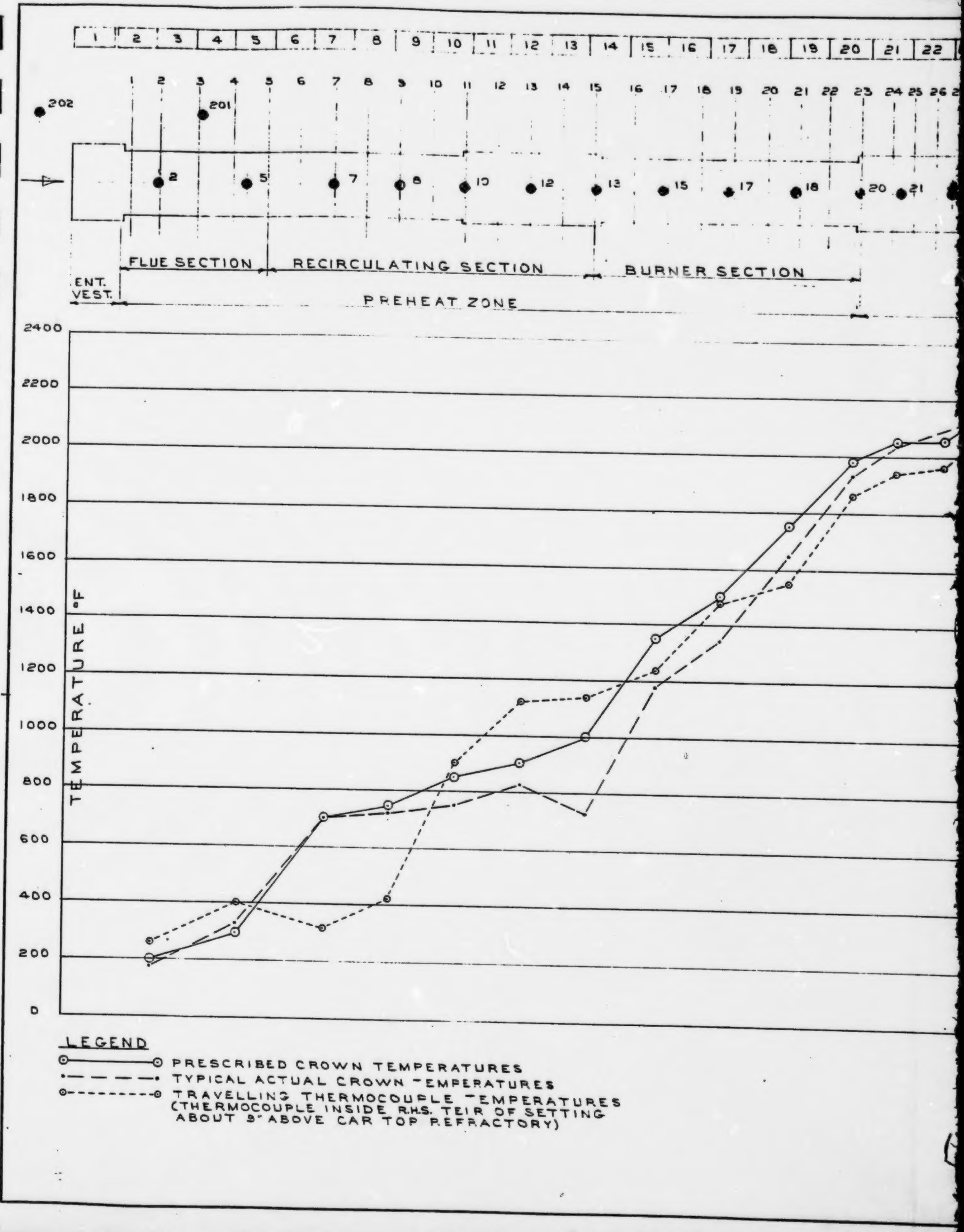
REVISIONS

KENT ENGINEERING LTD.
VANCOUVER B.C. CANADA

CHART IIIE

TUNNEL
KILN PRESSURE
PROFILES

SCALE
DESIGN BY
DRAWN BY
CHECKED BY
APPROVED BY
DATE
DRAWING NUMBER
REV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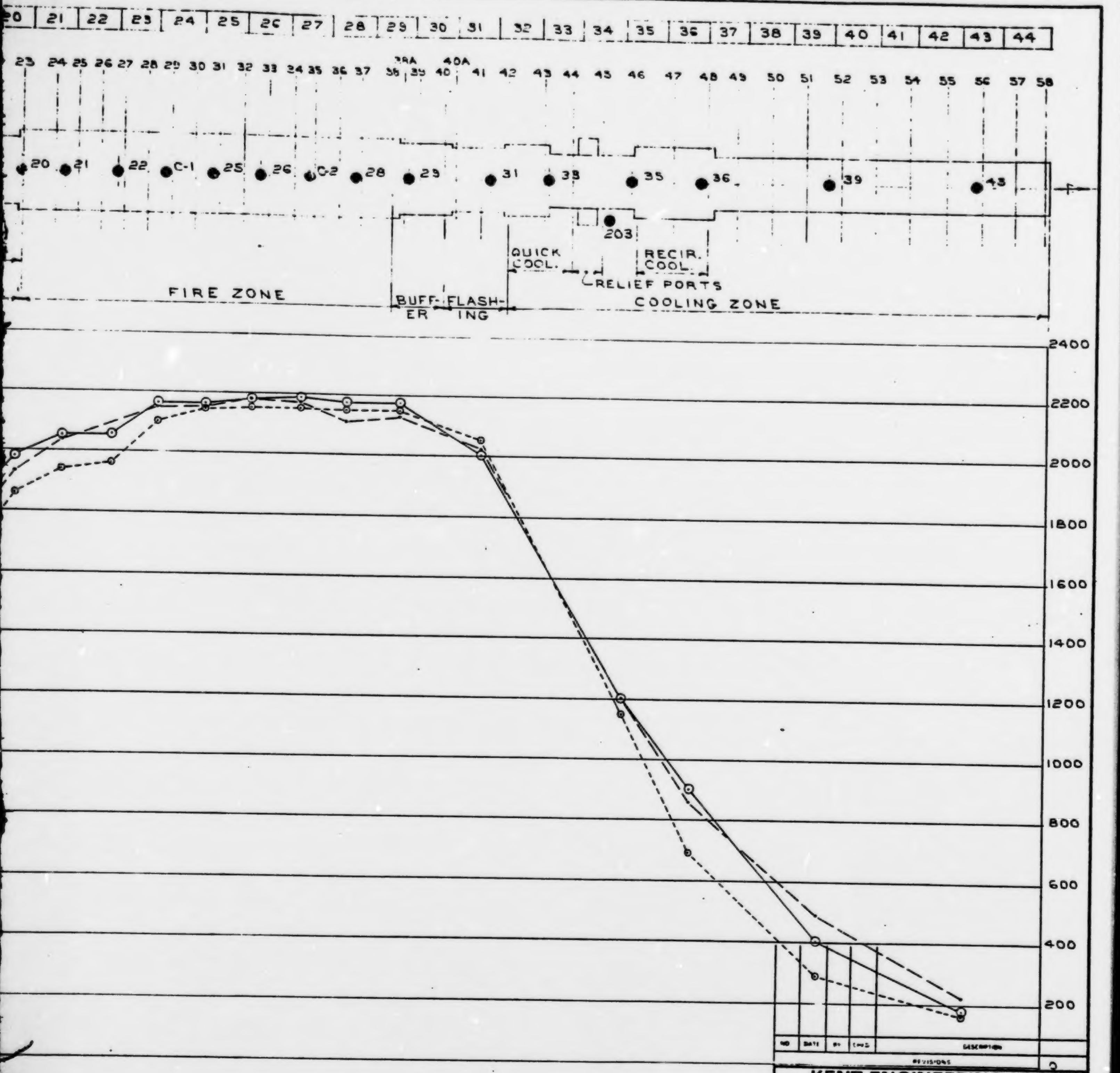
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
202
201
2 5 7 8 10 12 13 15 17 18 20 21
FLUE SECTION
RECIRCULATING SECTION
BURNER SECTION
ENT. VEST.
PREHEAT ZONE
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
TEMPERATURE °F
LEGEND
PRESCRIBED CROWN TEMPERATURES
TYPICAL ACTUAL CROWN TEMPERATURES
TRAVELLING THERMOCOUPLE TEMPERATURES (THERMOCOUPLE INSIDE R.H.S. TEIR OF SETTING ABOUT 3" ABOVE CAR TOP REFRACTORY)



KENT ENGINEERING LTD.
VANCOUVER B.C. CANADA

CHART IVE

PRESCRIBED & ACTUAL TEMPERATURE PROFILES FOR ACID BRICK

SCALE	CHECKED BY
DESIGN BY	APPROVED BY
DRAWN BY	DATE
DRAWING NUMBER	REV

APPENDIX 'A'

GENERAL SPECIFICATIONS

SINGLE TUNNEL DRYER: This single tunnel dryer will be of the kiln car type using clean waste heat from the tunnel kiln to dry the brick preparatory to entering the kiln. This dryer will be about 150'-0" long, have a tunnel width of 6'-0" and a tunnel height of 7'-3-3/8" from top of rail to underside of roof.

TUNNEL KILN: The tunnel kiln will be of the direct fired type using natural gas or Bunker C fuel oil; it will be 320'-0" long, have a tunnel width of 6'-0" and a height of 4'-3-1/4" from basic car top level to spring of crown.

GENERAL DESIGN

DRYER: The single tunnel dryer will be divided into five sections. There will be five cars in the charging section and four cars in each of the other four sections.

Clean hot air from the relief port of the kiln will be forced by the waste heat fan thru the cavity walls in the first section of the dryer discharging horizontally through openings in the inner wall to circulate through the setting. This section is exhausted through openings into a roof plenum whence it is picked up by a recirculating fan and forced back through the setting in the next section as described above. This is repeated in each section until the air enters the charging section whence it is exhausted.

A "Dutch Oven" is provided on the dryer so that the temperature of the entering hot air can be increased if desired.

There would be provided for this dryer, one (1) waste heat fan, one (1) exhaust fan and four (4) recirculating fans.

The cars in the dryer will be advanced by a 5" hydraulic ram mounted under the car at the charging end of the dryer.

KILN: The kiln will be designed for the efficient firing of your refractory brick and other structural clay products.

The kiln will be equipped with an airlock at the charging end to prevent the short-circuiting of draft when dharging a car. This airlock is created by a guillotine type door at both ends of a vestibule, each power operated.

The kiln will be equipped with an undercar hydraulic propeller, designed to move a kiln car from the transfer car, move it through the airlock and advance all the cars in the kiln one car length on a metered continuous push. The operation of this pusher and the airlock doors would be a time-proven automatic cycle basis.

The speed of travel of the cars in the kiln can be varied as desired by adjusting a variable flow control valve on the pusher pumping unit. The guillotine doors will be interlocked with the pusher system to prevent erroneous procedure -- by the kiln operator. There will be provided an alarm system and a pressure recording gauge for use with the pusher to provide a record of car movement into the kiln. The vestibule will be approximately 9'-4" long.

GENERAL DESIGN - Kiln (Continued)

The tunnel kiln car passes from the vestibule into the kiln, that is, into the main exhaust flue section where there will be a multiple number of damper controlled exhaust ports located at the bottom portion of the ware tunnel on each side of the kiln. These exhaust ports connect with brick lined flues in each kiln wall, which in turn connect with a brick lined exhaust plenum chamber located on top of the kiln. The exhaust fan will be located on a structural steel platform setting alongside the kiln. The intake of this fan will be connected with the exhaust plenum chamber. The exhaust of this fan will discharge into a brick lined exhaust stack. The exhaust flue section will cover a distance of approximately 26' -10".

Catwalks and ladders are to be provided as required to make the equipment accessible to the operator.

In the exhaust flue section the ware is heated up evenly with down-draft action prevailing.

The brick then pass into the recirculating sections. In this kiln there will be five recirculating sections in the charging end. Each section will be equipped with two high temperature alloy recirculating fans. The inlet of each fan is connected with the crown of the kiln. The outlet of each fan is connected with the brick lined flues in the side walls and these connected with port openings in the bottom portion of each side of the ware tunnel. The air discharge from these fans enters the tunnel at the bottom of the setting and circulates vertically upward through the setting, giving very even heat distribution. Each of these five recirculating sections will have two fans making a total of ten (10) fans in this recirculating section. There will be a booster furnace and booster burners for each of the last four sections, to permit an increase of the temperature of the air handled by each fan, as desired.

These five recirculating sections will cover a distance of approximately 60' -0".

The ware then passes into the preheat zone where the temperature is raised to prepare the ware for finish firing. This section will have 15 dual fuel North American burners on each side or a total of 30 burners for this section. This preheat zone will extend for approximately 48' -0".

The ware then passes into the main fire zone. There will be provided on each side of the kiln nineteen (19) burners or a total of thirty-eight (38) burners for this section.

As the ware passes through the main fire zone, the ware is evenly heated up, at a predetermined rate to the soaking temperature desired and the necessary soak maintained to properly fire your ware..

There will be two (2) automatic temperature control zones in the main fire zone. The main fire zone will be about 71' -0" long.

After the ware is properly fired, it passes into the discharge end where it is cooled at the proper rates in the various zones.

GENERAL DESIGN - Kiln (Continued)

After the ware leaves the fire zone, it will pass through a quick cooling section of approximately 12' -0" equipped with two (2) high temperature alloy recirculating fans. In this section the cooling rate will be rapid, accomplished by vigorous circulation of cooling air.

A relief port will be provided on each side of the kiln to bleed off the clean heated air not required for the operation of the tunnel kiln and which will be conducted to the dryer.

Following the relief port will be a recirculating zone of approximately 12' -0".

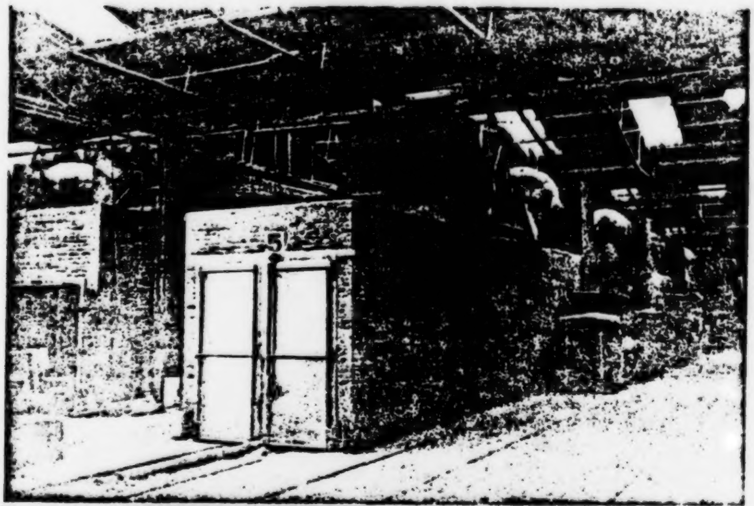
The distance from the end of the fire zone to the discharge end of the recirculating section will be about 30' -0". From the end of the recirculating section to the discharge end of the kiln will be about 74' -6".

The air supply fan, for direct cooling in the ware tunnel will be mounted on top of the kiln with the inlet connected to a short section of waste heat roof. This will enable the cooling fan to utilize air of a relatively constant temperature, thereby decreasing the variation from day to night and season to season.

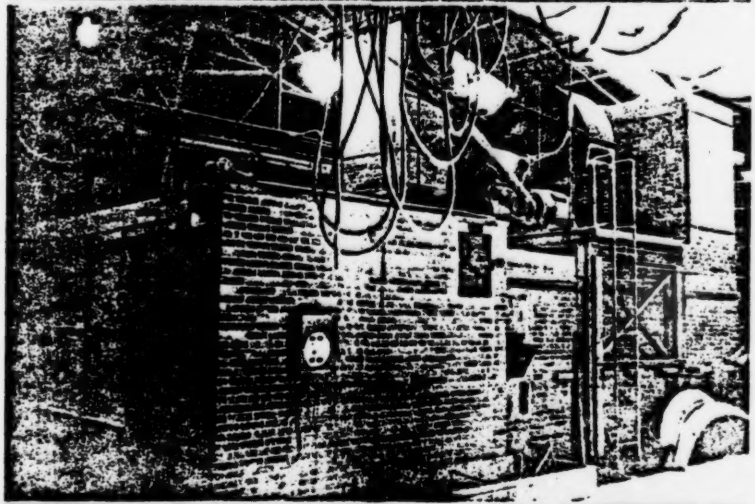
Silica refractories will be specified in the fire zone, semi-silica in the preheat and neck with lesser grades in the cooler portions of the kiln.

Catwalks, ladders, peepholes, pyrometer recording systems, instrument panel, under car cooling and other pertinent components are detailed in design.

APPENDIX B - PHOTOGRAPHS OF KILN AND DRYER



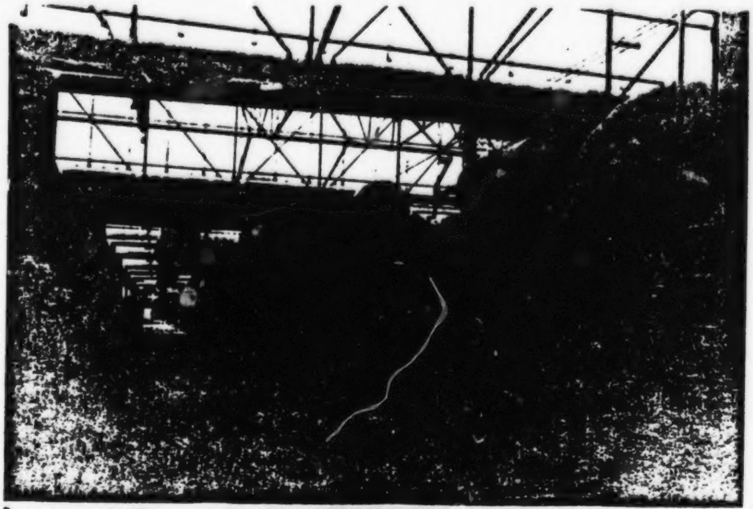
Charge End
of Dryer



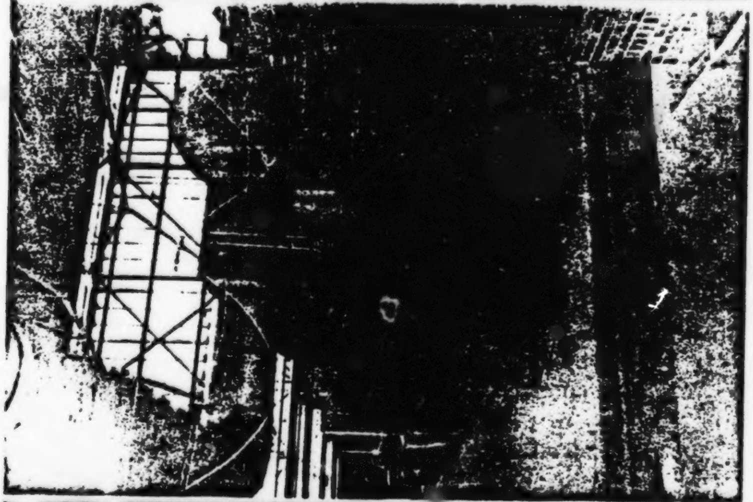
Charge End
of Kiln

Exit End
of Kiln

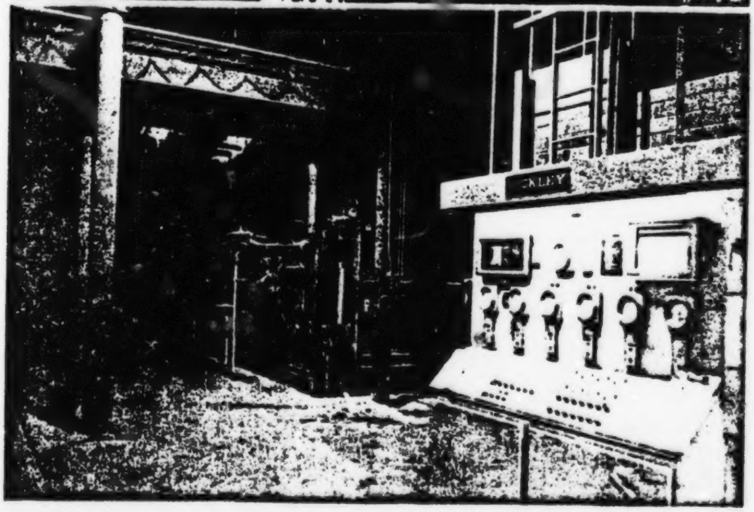
APPENDIX B - PHOTOGRAPHS OF KILN AND DRYER



Cooling Zone



Exit End of Dryer



Bickley
Shuttle
Kiln

APPENDIX C - COLLECTED AND MEASURED FIELD DATA

TABLE IC- NO. 2 TUNNEL KILN ATMOSPHERE OXYGEN READINGS

Date: May 2, 1985 - Instrument: Neotronics FEM Analyser - Product: Medium Duty Firebrick

Location in Kiln	Time	Percent Oxygen by Volume (Approx. % Excess Air)		
		Right Side	Left Side	Average or Single Point
Exhaust Fan Discharge	14:20			18.8
Start of Preheat	14:30		9.2(70)	
	15:30	12.0(120)		10.7
	16:25		11.0(98.7)	
Middle of Preheat	14:40		10.0(81.6)	
	15:40	12.6(134)		10.3
	16:28		8.4(60)	
End of Preheat	14:50		5.8	
	15:50	1.8(9)		1.4
	16:31		1.0(4.5)	
Flashing	15:55	17.2		13.2
	16:10		10.3(87)	
36" Relief Vent Duct	16:40			20.2
16" Relief Vent Duct	16:45			20.8

TABLE IIC- NO. 2 TUNNEL KILN PRESSURES

Date: May 2 & 3, 1985 - Instrument: Dwyer Magnehelic Pressure Gage
- Product: Medium Duty Firebrick

Location in Kiln	Pressure in Inches of Water		
	Right Side	Left Side	Average
Recirculating			
Start (9 ft. from discharge plenum)	-1.35	-1.35	-1.35
Middle (35 ft. from discharge plenum)	-0.95	-0.85	-0.90
End (12 ft. from end of zone)	-0.50	-0.50	-0.50
Preheat			
Start	-0.34	-0.37	-0.36
Middle	-0.075	-0.11	-0.092
End	+0.005	+0.005	+0.005
Flashing	+0.015	+0.010	+0.013
Recirculating Cooling Section (downstream end)	+0.045	+0.050	+0.048
Cooling Section (These readings obtained on May 3, 1985)			
6 ft. from end of recircul. cooling sec.	+0.050	+0.050	+0.050
12 ft. from end of recircul. cooling sec.	+0.045	+0.030	+0.040
24 ft. from end of recircul. cooling sec.	+0.035	+0.035	+0.035

Notes:
Recirculating zone pressure readings taken at upper inspection ports.

TABLE IIIC - NO. 2 TUNNEL KILN ATMOSPHERE OXYGEN READINGS

Date: May 16, 1985 - Instrument: Teledyne Model 320P - Product: Giant Red Brick

Location in Kiln	Percent Oxygen by Volume (Approx. % Excess Air)		
	Right Side	Left Side	Single Point or Average
Exhaust Fan Discharge			19.0
Middle of Recirculating	20.5	20.5	20.5
Start of Preheat	16.0	18.0	17.0
Middle of Preheat	9.2	11.7	10.5
End of Preheat	4.8	8.5	6.7
Flashing	6.6	9.6	7.1
Recirculating Cooling	20.5	20.5	20.5
36" o Relief Vent Duct			19.8
16" o Relief Vent Duct			21.0

Notes

(1) Measurements at exhaust fan and mid-recirculating zones not done at same time.

(2) Readings at any one measurement point varied generally 0.3 to 2 percent over a period of 5 to 20 minutes.

TABLE IVC- NO. 2 TUNNEL KILN PRESSURES

Date: May 16, 1985 - Instrument: Dwyer Magnehelic Pressure Gage
- Product: Giant Red Brick

Location in Kiln	Pressure in Inches of Water		
	Right Side	Left Side	Average
Recirculating			
Start (9 ft. from discharge plenum)	-0.70/-0.65	-0.75/-0.35	-0.78/-0.50
Middle (35 ft. from discharge plenum)	-0.50/-0.10	-0.50/-0.25	-0.50/-0.17
End (12 ft. from end of zone)	-0.30/-0.015	-0.30/-0.025	-0.30/-0.020
Preheat			
Start	-0.24	-0.24	-0.24
Middle	-0.070	-0.090	-0.08
End	+0.010	+0.005	+0.007
Flashing	+0.020	+0.020	+0.020
Recirculating Cooling Section (downstream end)	+0.065/+0.040	+0.050/+0.035	+0.057/+0.037
Cooling Section			
6 ft. from end of recirc.cooling sec.	+0.045	+0.050	+0.047
12 ft. from end of recirc.cooling sec.	+0.070	+0.045	+0.058
24 ft. from end of recirc.cooling sec.	+0.075	+0.060	+0.068

Notes

(1) Readings for Recirculating Preheat Zone and Recirculating Cooling Zone are given as Upper Part/Lower Port.

TABLE VC - NO. 2 TUNNEL KILN ATMOSPHERE OXYGEN READINGS

Date: May 28, 1985 - Instrument: Teledyne Model 990 - Product: Diatherm 17 Insul. Brick

Location in Kiln	Percent Oxygen by Volume			PPM Carbon Monoxide		
	RHS	LHS	Single Point or Average	RHS	LHS	Single Point or Average
Exhaust Fan Discharge			19.0			760
Middle of Recirculating	19.0	19.0	19.0	800	760	780
Start of Preheat	19.5	20.0	19.7	970	610	790
Middle of Preheat	20.0	19.0	19.5	360	540	450
End of Preheat	18.0	18.0	18.0	520	110	315
Flashing	20.0	18.5	19.3	0	0	0
Recirculating Cooling	21.0	21.0	21.0	0	0	0
36" o Relief Vent Duct			20.0			0
16" o Relief Vent Duct			20.6			0

TABLE VIC - TUNNEL KILN PRESSURES

Date: May 28, 1985 - Instrument: Dwyer Magnehelic Pressure Gage
- Product: Diatherm 17 Insul. Brick

Location in Kiln	Pressure in Inches of Water		
	Right Side	Left Side	Average
Recirculating			
Start (9' from discharge plenum)	-0.65/-0.55	-0.65/-0.32	-0.65/-0.44
Middle (35' from discharge plenum)	-0.50/-0.13	-0.50/-0.30	-0.50/-0.21
End (12' from end of zone)	-0.35/-0.025	-0.35/-0.05	-0.35/-0.037
Preheat			
Start		-0.28	
Middle		-0.11	
End		-0.045	
Flashing		-0.015	
Recirculating Cooling Section (downstream end)		+0.005/0	
Cooling Section			
6' from end of recirc.cooling sec.		0	
12' from end of recirc.cooling sec.		0	
24' from end of recirc.cooling sec.	0	0	

Notes

(1) Readings for Recirculating Preheat Zone and Recirculating Cooling Zone are given as Upper Port/Lower Port for sampling at upper and lower inspection ports.

(2) Pressures indicate little or no air flow in cooling section.

TABLE VIIC- NO. 2 TUNNEL KILN ATMOSPHERE OXYGEN AND CARBON MONOXIDE READINGS

Date: July 5, 1985 - Instrument: Teledyne Model 990
- Product: Acid Brick

Location in Kiln	Percent Oxygen by Volume			PPM Carbon Monoxide		
	RHS	LHS	Single Point or Average	RHS	LHS	Single Point or Average
Exhaust Fan Discharge			19.8			
Recirculating						
Start (5)*	18.5			25		
Middle (9)	19.0			15		
End (13)	20.7			15		
Preheat						
Start (15)	19.0	18.0 [19.1]	18.5	50		
Middle (19)	13.5	12.5	13.0	5		
End (22)	9.0	8.0	8.5	15		
Firing Zone						
End (38)	2.7 [7.5]	2.5 [10.9]	2.6 [9.2]	10	20 [400+]	15
Mid	[2.1]	[12.0]	[7.0]		[400+]	
Start	[6.9]	[13.5]	[10.2]		—	
Flashing (41)	13.0	7.0	10.0			
End of Fast Cooling Sec.(43)	21.0	18.5	19.2			
End of Recirc.Cooling Zone	21.0					
36" o Relief Vent Duct			19.5			
16" o Relief Vent Duct			-			

Note:
* Numbers in brackets denote kiln steel column or buckstay number.
** Values denoted [ ] obtained on Dec. 3, 1985.

TABLE VIIIC- TUNNEL KILN PRESSURES

Date: July 5, 1985 - Instrument: Dwyer Magnehelic Pressure Gage
- Product: Acid Brick

Location in Kiln	Pressure in Inches of Water		
	Right Side	Left Side	Average
Recirculating			
Start (5)*	-0.75/-0.65	-0.75/-0.30	-0.75/-0.47
Middle (9)	-0.55/-0.13	-0.50/-0.25	-0.52/-0.19
End (13)	-0.35/-0.025	-0.35/-0.030	-0.35/-0.027
Preheat			
Start (15)	-0.29	-0.24	-0.26
Middle (19)	-0.060	-0.050	-0.55
End (22)	0	0	0
Firing Zone			
End (38)	+0.015	+0.015	+0.015
Flashing (41)	+0.005	+0.005	+0.005
Relief Port (taken 24/7/85)	-0.02	-0.06	-0.04
End of Fast Cooling Section (43)	0	0	0
End of Recirc.Cooling Sec. (48)	+0.040/+0.025	+0.040/+0.015	+0.040/+0.020
Cooling Section			
(48/49)	+0.035	+0.040	
(51/52)	+0.040	+0.050	

Notes

* Numbers in brackets denote kiln steel column or buckstay number.

(1) Readings for Recirculating Preheat Zone and Recirculating Cooling Zone are given as Upper Port/Lower Port for sampling at upper and lower inspection ports.

(2) Pressures indicate little or no air flow in cooling section.

(3) Pressure at exit end of No. 5 Dryer was measured at -0.24" w.c.,0.46"w.c. at entrance.

(4) Pressure at kiln entrance was measured at -60"w.c.

TABLE VIIIC - TUNNEL KILN PRESSURE (Cont'd)

Date: August 1, 1985 Product or Ware: Acid Brick

Location in Kiln	Pressure in Inches of Water (w.c.)		
	Right Side	Left Side	Average
Firing Zone			
Beginning (23)	0	+0.005	+0.0025
1/4 length	+0.005	+0.01	+0.0075
Mid-length	+0.022	+0.01	+0.016
3/4 length	+0.005	0	+0.0025
End of Zone (37)	+0.02	+0.01	+0.015
Crown (32)			+0.02
Preheat			
Beginning	-0.33		-0.33
End	-0.005		-0.005
Kiln Exit	+0.01 at crown, +0.04 at car deck elevation		

Qualitative Test

Flame travel from a green stick inserted into tunnel just end of firing zone indicated an air flow stagnation zone.

TABLE IXC - SURFACE TEMPERATURES

Ware	Date	Location	Temperature ^{o}F
Acid brick	9/7/85	Kiln Firing Zone	
		Crown	302
		Side	230
	9/8/85	Kiln Sides	
		Mid recirculating zone	Absent
		Mid preheat zone	122
		Flashing and fast cooling	212
		Mid balance cooling	113
		Dryer	
		Side at mid-length	140
		Dryer Fans and Ducts	
		Waste heat fan (i.e. supply)	401
		Recirculating fan No. 4	311
		Recirculating fan No. 3	257
		Recirculating fan No. 2	248
		Recirculating fan No. 1	221
		Exhaust fan	176
Giant Red	16/5/85	Kiln Sides	
		Beginning preheat zone	131
		Mid preheat zone	176
		End preheat zone	230
		Beginning firing zone	266
		Mid firing zone	302
		End firing zone	302
		Flashing	212
		Beginning cooling zone	203
		Mid cooling zone	131
		Bickley Shuttle Kiln	
		Sides	221
		Ends	203

TABLE XC - TEMPERATURE OF WARE IN PROCESS

Ware	Date	Temperature, °F			
		Entering Dryer	Leaving Dryer (1)	Entering Kiln	Leaving Kiln
Med.Duty Firebrick	23/9/85	Ambient	392	392	
	26/9/85				248
Acid Brick	9/7/85	95	338	338(2)	150

Notes:
(1) Measured as surface temperature.

(2) Temperature of ware was found to be reduced to 194°F by the time it travelled in the kiln to the exhaust fan location apparently due to cooling by air infiltered at the entrance door.

TABLE XIC - WEIGHT OF CLAY AND WATER PER CAR

Ware	Weight Clay	Weight Water
Med.Duty Firebrick	11,917	893
Red Giants	7,104	452
Insulating Brick (Diatherm 17)	6,156	3,144
Acid Brick	10,472	1,632

TABLE XIIC - DRYER TEMPERATURE AND HUMIDITY READINGS

Ware	Date	Location	Temperature $^{\circ}$F		R.H.	Humidity Ratio
			Dry Bulb	Wet Bulb	%	(Lb.of water/Lb.dry air)
Insulating Brick Diatherm 17	26/9/85	Waste Heat Fan (i.e. supply)	458	121		0.011
		Recirculating Fan No. 4	405	148		0.130
		Recirculating Fan No. 3	332	146	2.6	0.145
		Recirculating Fan No. 2	285	140	4.3	0.115
		Recirculating Fan No. 1	240	120	4.4	0.051
		Exhaust Fan	181	103	7	0.029

Notes:
Pressures at dryer entrance and exit were 0.38"w.c. and 0.24" w.c. respectively and high air infiltration was evident. As a test, flow to the exhaust fan was throttled by means of an inlet damper until pressures at the entrance and exit dropped to 0.05"w.c. and 0.03"w.c. respectively. Within a period of 30 minutes, although the supply air temperature had dropped to 400°F, the exhaust air temperature had risen to 190°F and its humidity ratio to 0.040. (Compare to 458°F supply air temperature and exhaust air at 181°F and 0.029 humidity ratio.)

TABLE XIIIC - FUEL CONSUMPTION

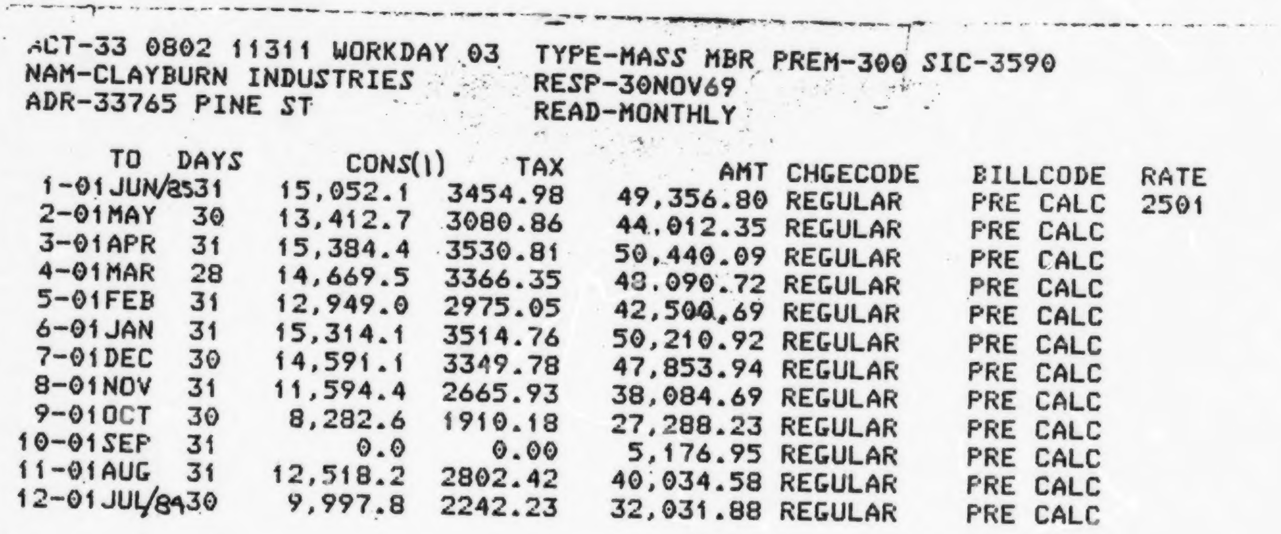
Ware	Date	Gas Consumption ft.^{3}/day	
		Operator's Log	Meter Reading(1)
Med.Duty Firebrick	23/9/85		468,000
(Straights)	2/5/85	500,000	
Giant Red	16/5/85	314,000	
Diatherm 17	27/5/85	255,000	
(Straights)	28/5/85	285,000	
Acid Brick	3/7/85	350,000	
(Straights)	5/7/85	425,000	
	9/8/85		364,000

(1) Meter readings obtained by measuring time for flow of 100 ft.^{3}, correcting for 60 psig. gas pressure (Factor = 5.07), and subtracting where applicable 24,000 ft.^{3}/day for predryer consumption.

Pressures measured at firing zone burners:
- Med. Duty Firebrick - Air, 9.5"w.c.; Gas 2.5"w.c.
- Acid Brick - Air, 11"w.c.; Gas 3"w.c.

TABLE XIVC - NATURAL GAS CONSUMPTION

(Record supplied by B.C. Hydro)



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ACT-33 0802 11311 WORKDAY 03  TYPE-MASS MBR PREM-300 SIC-3590
NAM-CLAYBURN INDUSTRIES       RESP-30NOV69
ADR-33765 PINE ST             READ-MONTHLY

    TO   DAYS        CONS(1)     TAX          AMT CHGECODE    BILLCODE  RATE
  1-01JUN/8531    15,052.1   3454.98    49,356.80 REGULAR     PRE CALC  2501
  2-01MAY   30    13,412.7   3080.86    44,012.35 REGULAR     PRE CALC
  3-01APR   31    15,384.4   3530.81    50,440.09 REGULAR     PRE CALC
  4-01MAR   28    14,669.5   3366.35    48,090.72 REGULAR     PRE CALC
  5-01FEB   31    12,949.0   2975.05    42,500.69 REGULAR     PRE CALC
  6-01JAN   31    15,314.1   3514.76    50,210.92 REGULAR     PRE CALC
  7-01DEC   30    14,591.1   3349.78    47,853.94 REGULAR     PRE CALC
  8-01NOV   31    11,594.4   2665.93    38,084.69 REGULAR     PRE CALC
  9-01OCT   30     8,282.6   1910.18    27,288.23 REGULAR     PRE CALC
 10-01SEP   31         0.0      0.00     5,176.95 REGULAR     PRE CALC
 11-01AUG   31    12,518.2   2802.42    40,034.58 REGULAR     PRE CALC
 12-01JUL/8430     9,997.8   2242.23    32,031.88 REGULAR     PRE CALC
```

(1) Consumption in millions of cubic feet.

TABLE XVC - LIST OF DRYER AND KILN FANS

Service	Table Rating				Service Rating				Description	
	CFM	S.P."w.c.	°F	RPM	CFM	S.P."w.c.	°F	RPM	Type	Size
Dryer										
Exhaust	14,856	3.00	70	955	14,856	2.60	150	956	J	33
Recir.No.1,No.2 No. 3 & No. 4	13,618	2.00	70	821	13,618	1.61	200	822	J	33
Waste Heat (Supply)	14,856	3.00	70	955	14,856	1.96	350	956	J	33
Kiln										
Exhaust	25,800	8.00	70	945	25,200	4.20	550	940	AE-6-BB	48
Under Car Cooling	10,523	3.00	70	860	10,450	3.00	70	858		
Cooling Air Supply Fan	16,094	1.50	70	833	16,350	1.50	70	841		
Quick Cooling Fans(2) (now removed)	4,270	4.00	70	1975	4,320	1.13	1400	1985	AE-6-BB	18"x7.5"
Turbo Blower (Combustion Air)	3,500	24 osi	70						324-K1-40	

Manufacturers
Fans - Robinson Ventilating Co.
Turbo-blower - North American Manufacturing Co.

TABLE XVIC - SUMMARY OF RESULTS OF AIR EMISSIONS SURVEY (1978)

Source	Sampling Date	Average Temp. (°F)	Orsat Analysis			Grains (DSCF)	ACFM	DSCFM	Remarks
			%CO_2	%O_2	%H_2O				
Kiln No. 1	Oct.12/78	410	0.8	19.0	6.8	0.003	26,650	15,100	PA-2845 App. 01
Kiln No. 2	Oct.12/78	475	1.2	18.3	6.0	0.014	47,600	25,250	PA-2845 App. 01
Twin Dryer	Oct.13/78	133	0.4	19.8	5.5	0.002	9,600	8,100	PA-2845 App. 02
Single Dryer	Oct.13/78	140	0.4	19.8	5.0	0.001	17,500	14,600	PA-2845 App. 03

ACFM - Actual Cubic Feet Per Minute at Stack Conditions

DSCFM - Dry Standard Cubic Feet Per Minute at 68 °F and 29.92" Hg.

TABLE XVIIC - SUMMARY OF TUNNEL KILN ATMOSPHERE OXYGEN CONCENTRATIONS

Ware	Oxygen Concentration in Percent by Volume (1)							
	Exh.Fan	Recir.Sec.	Preheat Sec.	Firing Zone	Flashing	Fast Cool	Recir.Cool	Hot Air Takeoff
Med. Duty Firebrick	18.8		10.7/103/1.4		-/13.2/-			20.2
Giant Red	19.0	-/20.5/-	17/10.5/6.7		-/7.1/-		-/-/20.5	21.0
Insul. Brick (Diatherm 17)	19.0	-/19.0/-	19.7/19.5/18.0		-/19.3/-		-/-/21.0	20.0
Acid Brick	19.8	18.5/19.0/ 20.7	18.5/13/8.5	-/-/2.6	-/10.0/-	-/-19.2	-/-/21.0	19.5

(1) Oxygen concentrations for sections and zones are listed as follows: At charge end/At middle/At exit

Kiln 2

TABLE XVIIIC - KILN OPERATING CONDITIONS

WARE Clayburn (mm)

CROWN THERMOCOUPLES	TEMPERATURES °F
2	200
5	600
7	1100
8	1200
10	1400
12	1500
13	1500
15	1600
17	1700
18	1800
20	1900
21	2100
22	2250
C-1	2280
25	2300
26	2320
C-2	2320
28	2320
29	2300
31	2210
33	1800
35	1480
36	1245
39	985
43	480
201	330
202	550

C-1 ZONE 2280 ~~2300~~ °F

C-2 ZONE 2320 ~~2340~~ °F

SCH. 16

EX. FAN % OPEN 100

COOL FAN % OPEN 14"

DRYERS NO. 5 TEMP. 550 °F

OLD BURNERS

	GAS	AIR
1	8	20
2	8	20

L + R

		GAS	AIR
CROWNS		3.2	W.O.
R. SIDE		3	12
L. SIDE		3	12
CROWNS		3.4	W.O.
R. SIDE		3	12
L. SIDE		3	12
PREHEAT CROWNS	1	6	✓
	2	6	
	3	6	
	4	6	
	5	5	
	6	5	W.O.
	7	3	
	8	3	
	9	3	
	10	3	
	11	3~~5~~	
	12	3~~5~~	
PREHEAT SIDES	1	6~~5~~	15
	2	6~~5~~	15
	3	5~~3~~	15
	4	3	15
	5	3	15
	6	3~~4~~	15
	7	3~~3~~	15

Kiln 2

KILN NO. 2

WARE Red

Nov/83

ROWN PLES Th.	TEMPERAT °F
2	100
5	365
7	880
8	1025
10	1150
12	1295
13	1325
15	1665
17	1745
18	1845
20	1975
21	2005
22	2010
C-1	2050
25	2060
26	2085
C-2	2070
28	2075
29	2075
31	1995
33	1970
35	1425
36	1140
39	570
43	240
201	330
202	535

C-1 ZONE 2050 °F

C-2 ZONE 2070 °F

SCH. 24

EX. FAN % OPEN 40

COOL FAN % OPEN 16"

DRYERS NO. 5 TEMP. 530 °F

		GAS	AIR
CROWNS		1.8	W.O.
R. SIDE		3	12
L. SIDE		3	12
CROWNS		2.0	W.O.
R. SIDE		3	12
L. SIDE		3	12
PREHEAT CROWNS	1		
	2		
	3		
	4		
	5		
	6	3.5	W.O.
	7	3	
	8		
	9		
	10		
	11		
	12		
PREHEAT SIDES	1	4	
	2	4	
	3	4	
	4	4	15
	5	4	
	6	3	
	7	3	

120

TABLE XVIIIC - KILN OPERATING CONDITIONS (CONT'D.)

WARE Acid Str. & Kilbar

THERMOC	TEMPERATURES °F
2	200
5	300
7	700
8	750
10	850
12	900
13	1000
15	1350
17	1500
18	1750
20	1980
21	2050
22	
C-1	2160
25	2160
26	2180
C-2	2185
28	2170
29	2170
31	2000
33	
35	1200
36	900
39	400
43	170
201	300
202	530

Kilbar - 2120"
C-1 ZONE
MM Strs. 2160°

Kilbar - 2140°
C-2 ZONE
MM Strs. 2185"

SCH. 12

EX. FAN % OPEN 50

COOL FAN % OPEN 12

DRYERS NO. 5 TEMP. 530°

			GAS	AIR
C-1 ZONE	CROWNS		2.4	WO
	R. SIDE		3	12
	L. SIDE		3	12
C-2 ZONE	CROWNS		2.6	WO
	R. SIDE		3	12
	L. SIDE		3	12
PREHEAT CROWNS		1	2.5	
		2	2.5	
		3	2.5	
		4	2.5	
		5	2.5	
		6	2	WO
		7	2	
		8	2	
		9	1.5	
		10	1.5	
		11	1.5	
		12	1.5	
PREHEAT SIDES		1	2.5	15
		2	2.5	15
		3	2.5	15
		4	2	15
		5	2	15
		6	2	15
		7	2	15

KILN NO. 2

May 18 3 WARE Diathermo 17 2½"

THERMOC	TEMPERA
2	125
5	310
7	580
8	620
10	655
12	760
13	555
15	930
17	1015
18	1155
20	1300
21	1400
22	1500
C-1	1500
25	1470
26	1490
C-2	1500
28	1460
29	1435
31	1280
33	1260
35	370
36	160
39	100
43	80
201	330
202	390

C-1 ZONE 1500°F

C-2 ZONE 1500°F

SCH. 15

EX. FAN % OPEN 50

COOL FAN % OPEN 4"

DRYERS NO. 5 TEMP. 400°F
430°F max

S/M Dryers
85°F/120°F

			GAS	AIR
C-1 ZONE	CROWNS		.8	W.O.
	R. SIDE		3	12
	L. SIDE		3.2	12
C-2 ZONE	CROWNS		.8	W.O.
	R. SIDE		3	12
	L. SIDE		3	12
PREHEAT CROWNS		1	8	WO
		2		
		3		
		4		
		5		
		6		
		7		
		8		
		9		
		10		
		11		
		12		
PREHEAT SIDES		1	1	WO
		2		
		3		
		4		
		5		
		6		
		7		

TABLE XIXC

OPERATORS' LOG SHEETS

LAYBURN

PROCESS CONTROL REPORT KILN No. 2

WARE Clayburn St. SCHEDULE 16 CARS/DAY FUEL Gas PUSHER PRESSURE 500 lbs/sq. in. DATE 2-5-85

TEMPERATURES IN °F BY THERMOCOUPLES

OF RY	CAR No.	TIME OF ENTRY	TIME	2	5	7	8	10	12	13	15	17	18	20	21	22	C-1	25	26	C-2	28	29	31	33	35	36	39	43	202	201	203
	3715	12.00	12 MID	210	510	1040	1120	1250	1385	1310	1650	1750	1930	2130	2200		2320	2325	2340	2340	2260	2270	2175		1335	1090	655	325	540	425	550
	3716	1.30	1 a.m.	210	510	1040	1120	1250	1385	1310	1650	1750	1930	2130	2200		2320	2325	2340	2340	2260	2270	2175		1335	1090	655	325	540	425	550
	3717	3.00	2	200	500	1050	1120	1245	1390	1315	1660	1760	1925	2125	2210		2320	2325	2350	2340	2260	2270	2180		1330	1090	660	330	545	425	555
	3718	4.30	3	200	500	1050	1120	1245	1390	1315	1660	1760	1925	2125	2210		2320	2325	2350	2340	2260	2270	2180		1320	1890	660	330	545	425	555
	3719	6.00	4	200	540	1035	1130	1200	1380	1305	1670	1770	1930	2115	2200		2320	2325	2350	2340	2255	2275	2165		1365	1060	640	315	540	430	550
	3720	7.30	5	200	540	1035	1130	1200	1380	1305	1670	1770	1930	2115	2200		2320	2325	2350	2340	2255	2275	2165		1365	1060	640	315	540	430	550
	3721	9.00	6	240	560	1035	1140	1220	1420	1340	1660	1750	1935	2120	2205		2320	2330	2345	2340	2260	2275	2180		1390	1080	645	325	545	400	620
	3722	10.30	7	240	560	1025	1140	1220	1420	1340	1660	1750	1925	2120	2205		2320	2330	2345	2340	2260	2275	2180		1390	1080	645	325	545	400	620
	3714	12.00	8	120	505	1035	1115	1170	1385	1340	1675	1750	1930	2135	2220		2320	2325	2345	2340	2260	2285	2190		1460	1160	645	325	565	400	645
	3713	1.30	9	120	505	1035	1115	1170	1385	1340	1675	1750	1930	2135	2220		2320	2325	2345	2340	2260	2285	2190		1460	1160	645	325	565	400	645
	3712	3.00	10	130	490	1045	1165	1170	1395	1360	1700	1750	1935	2130	2220		2320	2320	2340	2340	2260	2285	2190		1460	1175	660	325	540	420	610
	3711	4.30	11	130	490	1045	1165	1170	1395	1360	1700	1750	1935	2130	2220		2320	2320	2340	2340	2260	2285	2190		1460	1175	660	325	540	420	610
	3708	6.00	12 NOON	130	505	1060	1190	1210	1390	1345	1710	1750	1925	2110	2200		2320	2325	2350	2340	2260	2285	2200		1520	1190	720	310	555	410	645
	3709	7.30	1 p.m.	130	505	1060	1190	1210	1390	1345	1710	1750	1925	2110	2200		2320	2325	2350	2340	2260	2285	2200		1520	1190	720	310	555	410	645
	3725	9.00	2	110	500	1040	1140	1225	1430	1340	1700	1760	1925	2110	2200		2320	2325	2350	2340	2260	2285	2200		1535	1200	730	310	550	405	645
	3728	10.30	3	110	500	1040	1140	1225	1430	1340	1700	1760	1925	2110	2200		2320	2325	2350	2340	2260	2275	2200		1535	1200	730	310	550	405	645
			4	115	520	1085	1160	1235	1430	1330	1680	1760	1920	2110	2175		2300	2320	2350	2340	2260	2275	2190		1560	1230	750	340	540	410	655
			5	115	520	1085	1160	1235	1450	1330	1680	1760	1920	2110	2175		2300	2320	2350	2340	2260	2275	2190		1560	1230	750	340	540	[illegible]	655
			6	130	515	1080	1225	1270	1445	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2195		2300	2315	2345	2340	2265	2290	2195		1550	1240	785	385	555	405	650
			7	130	515	1080	1225	1270	1445	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2195		2300	2315	2345	2340	2265	2290	2195		1550	1240	785	385	555	405	650
			8	125	540	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1695	[illegible]	[illegible]	[illegible]		2300	2320	2340	2340	2265	2290	2200		1535	1235	790	320	555	375	630
			9	125	505	[illegible]	[illegible]	1300	1455	[illegible]	[illegible]	1695	[illegible]	[illegible]	[illegible]		2300	2320	2340	2340	2265	2290	2200		1535	1235	790	320	555	375	630
			10	260	535	1110	[illegible]	1315	[illegible]	[illegible]	[illegible]	1695	[illegible]	[illegible]	[illegible]		2300	2320	2345	2340	2265	2290	2200		1535	1245	810	415	560	400	[illegible]
			11	260	535	1110	1220	1315	1430	[illegible]	[illegible]	1695	[illegible]	[illegible]	2195		2300	2320	2345	2340	2265	2290	2200		1535	1245	810	415	560	400	[illegible]
jective →				200	600	1100	1200	1400	1500	1530	1600	1700	1800	1900	2100	2250	2280	2300	2320	2320	2320	2300	2210		1480	1245	985	480	550	330	

620
570
50

USTRIES LTD.

CLAYBURN

PROCESS CONTROL REPORT KILN No. 2

WARE Acid MM STKS SCHEDULE 12 CARS/DAY FUEL GAS PUSHER PRESSURE 400 lbs/sq. in. DATE 5/7/85

TEMPERATURES IN °F BY THERMOCOUPLES

IME OF ENTRY	CAR No.	TIME OF ENTRY	TIME	2	5	7	8	10	12	13	15	17	18	20	21	22	C-1	25	26	C-2	28	29	31	33	35	36	39	43	202	201	203
	4723	12	12 MID	170	335	720	760	820	890	765	1205	1370	1650	1925	2035		2150	2150	2180	2175	2100	2115	2000		1170	865	500	235	505	365	590
	4722	2	1 a.m.	170	335	720	760	820	890	765	1205	1370	1650	1925	2035		2150	2150	2180	2175	2100	2115	2000		1170	865	500	235	505	365	590
	4725	4	2	170	330	710	745	825	885	780	1225	1380	1660	1920	2030		2150	2155	2185	2175	2105	2125	2000		1155	850	490	240	505	370	[illegible]
	4724	6	3	170	330	710	745	825	885	780	1225	1380	1660	1920	2030		2150	2155	2185	2175	2105	2125	2000		1155	850	490	240	505	270	[illegible]
	4729	8	4	200	325	715	735	815	880	775	1240	1400	1665	1940	2045		2150	2150	2190	2175	2105	2130	2010		1135	840	485	230	510	360	550
	4728	10	5	200	325	715	735	815	880	775	1240	1400	1665	1940	2045		2150	2150	2190	2175	2105	2130	2010		1135	840	485	230	510	360	550
	4727	12	6	170	320	700	735	805	860	755	1220	1410	1675	1940	2050		2150	2150	2185	2175	2100	2125	2010		1155	830	480	225	505	365	560
	4726	2	7	170	320	700	735	805	860	755	1220	1410	1675	1940	2050		2150	2150	2185	2175	2100	2125	2010		1155	830	480	225	505	365	[illegible]
	4730	4	8	175	320	705	730	790	855	735	1210	1420	1710	1945	2055		2150	2155	2180	2175	2100	2125	2015		1160	830	480	220	520	355	585
	4731	6	9	175	320	705	730	790	855	735	1210	1420	1710	1945	2055		2150	2155	2180	2175	2100	2125	2015		1160	830	480	220	520	355	585
	4702	8	10	185	320	735	730	780	845	750	1240	1420	1710	1950	2050		2150	2155	2185	2175	2105	2130	2010		1120	830	470	210	510	355	520
	4732	10	11	185	320	735	730	780	845	750	1240	1420	1710	1950	2050		2150	2155	2185	2175	2105	2130	2010		1170	830	470	210	510	355	520
			12 NOON	170	330	725	760	780	855	760	1220	1450	1720	1960	2060		2150	2160	2185	2175	2100	2110	2000		1150	830	465	200	520	360	560
			1 p.m.	170	330	725	760	780	855	760	1220	1450	1720	1960	2060		2150	2160	2185	2125	2100	2110	2000		1150	830	465	200	520	360	560
			2	180	330	730	750	800	865	730	1210	1410	1680	1955	2060		2150	2160	2185	2125	2100	2120	2000		1150	820	465	200	520	355	520
			3	180	330	730	750	800	865	730	1210	1410	1680	1955	2060		2150	2160	2185	2175	2100	2120	2000		1150	820	465	200	527	[illegible]	520
			4	160	330	700	730	785	835	730	1180	1405	1680	1950	2050		2150	2155	2180	2175	2100	2120	2000		1150	830	480	205	530	355	565
			5	160	330	700	730	785	835	730	1180	1405	1680	1950	2050		2150	2155	2180	2175	2100	2120	2000		1150	830	480	205	530	355	565
			6	150	330	710	750	790	845	725	1180	1385	1685	1940	2050		2150	2150	2180	2175	2100	2120	2010		1160	845	485	220	530	350	575
			7	150	330	710	750	790	845	725	1120	1385	1685	1940	2050		2150	2150	2180	2175	2100	2120	2010		1160	845	485	220	530	350	575
			8	140	330	720	740	780	850	745	1200	1340	1660	1945	2050		2150	2155	2185	2175	2105	2125	2005		1160	835	485	220	515	350	570
			9	140	330	720	740	780	850	745	1200	1340	1660	1945	2050		2150	2155	2185	2175	2105	2125	2005		1160	835	485	220	515	350	570
			10	130	325	740	715	790	840	745	1180	1370	1650	1940	2050		2150	2155	2185	2175	2100	2120	2005		1140	835	490	230	520	340	560
			11	130	325	740	715	790	840	745	1180	1370	1650	1940	2050		2150	2155	2185	2175	2100	2120	2005		1140	835	490	230	530	340	560

465
425
40

AYBURN

PROCESS CONTROL REPORT KILN No. 2

WARE D17 2½" SCHEDULE 15 CARS/DAY FUEL GAS PUSHER PRESSURE 400 lbs/sq. in. DATE 27-5-85

TEMPERATURES IN °F BY THERMOCOUPLES

OF RY	CAR No.	TIME OF ENTRY	TIME	2	5	7	8	10	12	13	15	17	18	20	21	22	C-1	25	26	C-2	28	29	31	33	35	36	39	43	202	201	203
	3811	12-	12 MID	225	290	605	635	650	725	590	930	1020	1125	1280	1375		1500	1460	1500	1500	1460	1475	1310		430	265	220	160	415	335	245
	3812	1-36	1 a.m.	225	290	605	635	650	725	590	930	1020	1125	1280	1375		1500	1460	1500	1500	1460	1475	1310		430	265	220	160	415	335	245
	3813	3-12	2	240	290	600	635	650	735	550	925	1010	1140	1275	1380		1500	1460	1505	1500	1450	1460	1310		435	255	210	160	405	330	250
	3814	4-48	3	240	290	600	635	650	735	550	925	1010	1140	1295	1380		1500	1460	1505	1500	1450	1460	1310		435	255	210	160	405	330	250
	3815	6-24	4	230	295	610	630	645	730	570	920	1020	1130	1290	1380		1500	1465	1500	1500	1460	1465	1325		430	260	215	160	410	335	240
	3816	8-	5	230	295	610	630	645	730	570	920	1020	1130	1290	1380		1500	1465	1500	1500	1460	1465	1305		430	260	215	160	410	335	240
	3817	9-36	6	260	290	600	625	640	740	550	925	1025	1145	1285	1380		1500	1450	1500	1500	1460	1475	1315		430	250	205	150	415	340	260
	3818	11-12	7	260	290	600	625	640	740	550	925	1025	1145	1285	1380		1500	1450	1500	1500	1460	1475	1315		430	250	205	150	415	340	260
	3819	12-48	8	265	290	600	615	640	730	580	940	1020	1150	1280	1375		1500	1450	1485	1500	1460	1485	1325		445	255	200	150	420	335	270
	3820	2-24	9	265	290	600	615	640	730	580	940	1020	1150	1280	1375		1500	1450	1485	1500	1460	1485	1325		445	255	200	150	420	335	270
	3821	4-	10	290	290	610	625	640	740	595	945	1020	1160	1285	1375		1500	1455	1510	1500	1455	1475	1320		460	255	205	150	415	335	275
	3822	5-36	11	290	290	610	625	640	740	595	945	1020	1160	1285	1375		1500	1455	1510	1500	1455	1475	1320		460	255	205	150	415	335	275
	3823	7-12	12 NOON	290	290	610	620	635	740	605	945	1035	1165	1300	1385		1500	1435	1500	1500	1455	1465	1315		440	260	205	150	415	340	270
	3824	8-48	1 p.m.	290	290	610	620	635	740	605	945	1035	1165	1300	1385		1500	1435	1500	1500	1455	1465	1315		440	260	205	150	415	340	270
	3825	10-24	2	255	320	610	630	640	740	600	915	985	1130	1290	1385		1500	1465	1505	1500	1450	1470	1310		445	250	210	150	420	325	270
			3	255	320	610	630	640	740	600	915	985	1130	1290	1385		1500	1465	1505	1500	1450	1470	1310		445	250	210	150	420	325	270
			4	275	305	620	635	645	740	570	935	1000	1165	1285	1375		1500	1470	1520	1500	1450	1460	1300		435	250	205	150	415	335	[illegible]
			5	275	305	620	635	645	740	570	935	1000	1165	1285	1375		1500	1470	1520	1500	1450	1460	1300		435	250	205	150	415	335	[illegible]
			6	290	305	625	645	650	745	575	945	1035	1160	1290	1375		1500	1465	1505	1500	1445	1440	1300		425	255	[illegible]	145	[illegible]	345	[illegible]
			7	290	305	625	645	650	745	575	945	1035	1160	1290	1375		1500	1465	1505	1500	1445	1440	1300		425	255	[illegible]	145	[illegible]	345	[illegible]
			8	260	305	630	655	670	755	610	955	1030	1170	1300	1390		1500	1445	1485	1500	1445	1450	1290		410	255	200	140	[illegible]	[illegible]	[illegible]
			9	[illegible]	305	630	655	670	755	610	955	1030	1170	1300	1390		1500	1445	1485	1500	1445	1450	1290		410	255	200	140	[illegible]	[illegible]	[illegible]
			10	290	325	635	660	675	760	580	940	1045	1175	1305	[illegible]		1500	[illegible]	1495	1500	1455	1470	1300		415	245	200	140	410	[illegible]	[illegible]
			11	210	325	635	660	675	760	580	940	1045	1175	1305	[illegible]		1500	1460	1445	1500	1455	1470	1300		415	245	200	140	[illegible]	[illegible]	[illegible]

$$\begin{array}{r} 307\overset{3}{\cancel{4}}7 \\ 30719 \\ \hline 28 \end{array}$$

CLAYBURN

PROCESS CONTROL REPORT KILN No. 2

WARE RED 8" GIANTS SCHEDULE 27 CARS/DAY FUEL GAS PUSHER PRESSURE 500 lbs/sq. in. DATE 16-5-85

TEMPERATURES IN °F BY THERMOCOUPLES

ME OF ENTRY	CAR No.	TIME OF ENTRY	TIME	2	5	7	8	10	12	13	15	17	18	20	21	22	C-1	25	26	C-2	28	29	31	33	35	36	39	43	202	201	203
	3481	12	12 MID	115	335	8[illegible]	920	970	1150	1015	1515	1615	1730	1865	1925		2050	2080	2090	2070	2025	2045	1980		1440	1175	820	440	530	320	660
	3474	12-53	1 a.m.	115	335	8[illegible]	920	970	1150	1015	1515	1615	1730	1865	1925		2050	2080	2090	2070	2025	2045	1980		1440	1175	820	440	530	320	660
	3473	1-47	2	110	340	875	910	960	1105	1025	1480	1570	1720	1870	1915		2050	2070	2085	2070	2025	2045	1980		1465	1175	825	445	520	325	645
	3472	2-40	3	110	340	875	910	960	1105	1025	1480	1570	1720	1870	1915		2050	2070	2085	2070	2025	2045	1980		1465	1175	825	445	520	325	645
	3691	3-33	4	110	345	865	925	955	1100	1010	1510	1600	1700	1865	1935		2050	2075	2095	2070	2025	2040	1980		1400	1175	785	435	525	320	655
	3690	4-27	5	110	345	865	925	955	1100	1010	1510	1600	1700	1865	1935		2050	2075	2095	2070	2025	2040	1980		1460	1175	785	435	525	320	655
	3689	5-20	6	120	350	855	930	960	1130	1005	1445	1620	1700	1865	1930		2050	2070	2085	2070	2025	2040	1975		1445	1160	765	420	505	305	635
	3971	6-13	7	120	350	855	930	960	1130	1005	1445	1620	1700	1865	1930		2050	2070	2085	2070	2025	2040	1975		1445	1160	765	420	505	305	635
	3688	7-06	8	110	370	875	925	980	1170	1090	1500	1575	1680	1900	1940		2050	2080	2090	2070	2025	2035	1975		1440	1150	740	410	510	320	660
	3687	8	9	110	370	875	925	980	1170	1090	1500	1575	1680	1900	1940		2050	2080	2090	2070	2025	2035	1975		1440	1150	740	410	510	320	660
	3686	8-53	10	105	380	875	940	975	1160	1070	1530	1620	1720	1880	1920		2050	2060	2070	2070	2015	2030	1970		1450	1150	750	380	520	330	675
	3685	9-47	11	105	380	875	940	975	1160	1070	1530	1620	1720	1880	1920		2050	2060	2070	2070	2015	2030	1970		1450	1150	750	380	520	330	675
	3692	10-40	12 NOON	120	375	900	935	975	1150	1035	1510	1610	1735	1825	1925		2050	2075	2080	2070	2020	2045	1975		1450	1150	750	390	510	335	660
	3694	11-33	1 p.m.	120	375	900	935	975	1150	1035	1510	1610	1735	1875	1925		2050	2075	2080	2070	2020	2045	1975		1450	1150	750	390	510	335	640
	3669	12 27	2	120	385	900	960	990	1160	1050	1510	1590	1695	1880	1930		2050	2065	2085	2080	2020	2045	1980		1460	1160	740	390	530	340	675
	3672	1-20	3	120	385	910	960	990	1160	1050	1510	1590	1695	1880	1930		2050	2065	2085	2080	2020	2045	1980		1460	1160	740	390	530	340	675
	3671	2-13	4	130	385	895	965	995	1170	1065	1505	1605	1670	1860	1910		2050	2075	2085	2080	2020	2050	1980		1460	1125	745	375	535	350	675
	3670	3-06	5	130	385	895	965	995	1170	1065	1505	1605	1670	1860	1910		2050	2075	2085	2080	2020	2050	1980		1460	1125	745	375	535	350	675
	3673	4	6	130	390	910	975	1020	1170	1075	1515	1605	1680	1865	1910		2050	2075	2085	2080	2025	2050	1980		1465	1180	750	380	535	345	680
	3674	4-53	7	130	390	910	975	1020	1120	1075	1515	1605	1680	1865	1910		2050	2075	2085	2080	2025	2050	1980		1465	1180	750	380	535	345	680
	3675	5-47	8	130	395	920	1005	1045	1170	1100	1535	1605	1690	1870	1920		2050	2075	2090	2080	2025	2050	1975		1475	1195	775	380	550	340	685
	3713	6-40	9	130	395	920	1005	1045	1170	1100	1535	1605	1690	1870	1920		2050	2075	2090	2080	2025	2050	1975		1475	1195	775	380	560	340	685
	3714	7-33	10	120	380	910	985	1045	1210	1105	1555	1650	1750	1890	1940		2050	2080	2095	2080	2020	2050	1985		1440	1185	790	390	545	340	650
	3693	8-27	11	120	390	910	985	1045	1210	1105	1556	1650	1750	1890	1940		2050	2080	2095	2080	2030	2050	1985		1440	1185	790	390	545	340	650
	4421	9-20																													
	4422	10-13																													
	4482	11-06																													

570,000

CLAYBURN

PROCESS CONTROL REPORT KILN No. 2

WARE CLAYBURN St. SCHEDULE 16 CARS/DAY FUEL Gas PUSHER PRESSURE 500 lbs/sq. in. DATE 3-5-85

TEMPERATURES IN °F BY THERMOCOUPLES

TIME OF ENTRY	CAR No.	TIME OF ENTRY	TIME	2	5	7	8	10	12	13	15	17	18	20	21	22	C-1	25	26	C-2	28	29	31	33	35	36	39	43	202	201	203
	2729	12.00	12 MID	140	500	1080	1210	1285	1505	1465	1720	1730	1895	2080	2180		2300	2320	2345	2340	2260	2285	2200		1530	1220	815	400	550	400	630
	3730	1.30	1 a.m.	140	500	1080	1210	1285	1505	1465	1720	1730	1895	2080	2180		2300	2320	2345	2340	2260	2285	2200		1530	1220	815	400	550	400	630
	3731	3.00	2	240	495	1075	1185	1260	1475	1475	1720	1740	1885	2090	2180		2300	2320	2345	2340	2265	2285	2200		1550	1225	825	405	550	370	645
	3732	4.30	3	240	495	1075	1185	1260	1475	1475	1720	1740	1885	2090	2180		2300	2320	2345	2340	2265	2285	2200		1550	1225	825	405	550	370	645
	3733	6.00	4	115	455	1010	1125	1240	1460	1455	1735	1755	1885	2080	2180		2500	2320	2340	2340	2265	2290	2200		1555	1250	820	425	555	385	635
	3734	7.30	5	115	455	1010	1125	1240	1460	1455	1735	1755	1885	2080	2180		2300	2320	2340	2340	2265	2290	2200		1555	1250	820	425	555	385	635
	3735	9.00	6	120	465	1035	1135	1245	1435	1415	1725	1735	1865	2085	2185		2300	2320	2345	2340	2270	2290	2200		1560	1255	810	420	560	380	665
	3726	10.30	7	120	465	1035	1135	1245	1435	1415	1725	1735	1865	2085	2185		2300	2320	2345	2340	2270	2290	2200		1560	1255	810	420	560	380	665
	3646	12.00	8	115	455	1020	1155	1245	1455	1420	1705	1740	1890	2085	2180		2300	2315	2345	2340	2265	2285	2200		1540	1250	800	425	550	395	625
	3647	1.30	9	115	455	1020	1155	1245	1455	1420	1705	1740	1890	2085	2180		2300	2315	2345	2340	2265	2285	2200		1540	1250	800	425	550	395	625
	3648	3.00	10	130	460	1010	1135	1240	1435	1450	1710	1740	1880	2065	2165		2280	2300	2335	2340	2265	2285	2200		1520	1250	800	410	560	390	625
		4.30	11	130	460	1010	1135	1240	1435	1450	1710	1740	1880	2065	2165		2280	2300	2335	2340	2265	2285	2200		1520	1250	800	410	560	390	625
		6.00	12 NOON	110	480	1035	1140	1260	1430	1400	1705	1725	1875	2060	2150		2280	2295	2320	2320	2255	2280	2200		1520	1240	800	420	555	390	615
		7.30	1 p.m.	110	480	1035	1140	1260	1430	1400	1705	1725	1875	2060	2150		2280	2295	2320	2320	2255	2280	2200		1520	1240	800	420	555	390	615
		9.00	2	110	485	1050	1115	1205	1435	1425	1700	1740	1890	2060	2160		2280	2295	2320	2320	2250	2280	2200		1530	1245	810	435	560	405	665
		10.30	3	110	485	1050	1115	1205	1435	1425	1700	1740	1890	2060	2160		2280	2295	2320	2320	2250	2280	2200		1530	1245	810	435	560	405	665
			4																												
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HARROP
INDUSTRIES, INC.

Laboratory services in THERMAL ANALYSIS, MATERIALS TESTING, CUSTOM FIRING, AND CLAY TESTING.

Harrop Industries offers services from rapid, routine materials analysis, to investigations requiring in-depth studies for solutions to difficult thermal problems. Our "pilot-plant-in-a-box" concept saves time, labor, and money by determining the properties of materials on a schedule compatible with the overall project requirements, but without the capital expenditure. Basic research, product or process development, and full scale production activities can benefit from this unique service.

Combinations of Differential Thermal Analysis (DTA), Thermal Gravimetric Analysis (TGA), and Thermal Dilatometric Analysis (TDA) are handled by a thoroughly trained, highly competent staff with many years of experience in obtaining and interpreting thermal date.

A newly expanded firing service featuring both gas and electric kilns is available for research, development, and industrial applications. Harrop has the proper firing capabilities for 1600°C+, in special atmospheres with large or small setting volumes.

THERMAL ANALYSIS TECHNIQUES

Thermal analysis at Harrop is primarily concerned with three distinct types of thermal investigations:

A. Differential Thermal Analysis (DTA)
—This supplies a thermal "fingerprint" of a material, detecting heat release or heat absorption caused by chemical and physical changes within the material during heating and cooling.
Maximum temperature: 1600°C.

B. Thermal Gravimetric Analysis (TGA)
—The weight change of a material as a function of temperature during thermal processing is determined with TGA. Cahn electrobalance is a feature of this process.
Maximum temperature: 1600°C.

C. Thermal Dilatometric Analysis (TDA)
—Both reversible and irreversible linear change in length of a specimen during heating and cooling is measured.
Maximum temperature: 1600°C.
—Cryogenic dilatometry is now included in Harrop's total concept of thermal analysis. Ceramics, metals, and plastics can be investigated in temperature ranges of -180° to 500°C.

Harrop offers thermal analysis testing in air, O_2, Ar, He, N_2 and other atmospheres.
—Two dilatometer systems are available to test both small fine-grained samples and large coarse-grained materials.

The technical staff at Harrop has pioneered investigations of controlled combustion atmospheres and water vapor additions in ceramic firing applications. Whether you require oxidizing or reducing combustion atmospheres, Harrop has the capability and experience to provide exacting test conditions and practical interpretations of test results.

TABLE XXC (Cont'd)

Areas Of Research And Quality Control Applications	CERAMICS								
	WHITE-WARES	CLAYS	REFRACTORIES	MINERALS RAW MATERIALS	GLASS	CEMENTS	METALS	PLASTICS	CHEMICALS FUELS
DEHYDRATION-HYDRATION	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA		DTA-TGA TDA			DTA-TGA TDA
OXIDATION-REDUCTION	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA		DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA
PHASE TRANSITION	DTA-TGA	DTA-TGA	DTA-TGA	DTA-TGA	DTA-TGA	DTA	DTA-TGA	DTA-TGA	DTA-TGA
DECOMPOSITION	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA	DTA-TGA	DTA-TGA	DTA-TGA	DTA-TGA
GAS EVOLUTION	DTA-TGA	DTA-TGA	DTA-TGA	DTA-TGA	DTA-TGA	DTA-TGA	DTA-TGA	DTA-TGA	DTA-TGA
THERMOCHEMICAL REACTIONS	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA
PHYSICAL CHARACTERIZATION-IDENTIFICATION	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA TGA TDA	DTA-TGA TDA	DTA-TGA TDA
FIRING CYCLE DEVELOPMENT	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA	DTA-TGA	DTA-TGA TDA	DTA-TGA TDA	DTA-TGA

Examples of diverse applications of thermal analysis and material testing in aiding industry, education, and research are cited in this chart.

LABORATORY AND PILOT PLANT KILN FACILITIES

Harrop maintains both gas-fired and electric kilns to provide the thermal processing capability so often required on short notice, but which are not always readily obtained. Whether your program requires one firing or many, Harrop can provide the kiln for the job. Convenience and availability, without capital expenditure, are offered.

Kilns include:

GAS-FIRED

Shuttle kiln with 20 cu. ft. capacity and 1575°C operating temperature, complete with atmosphere control capability.

ELECTRIC

Temperature ranges to 1600°C. Gas-tight construction for special atmosphere firings. Setting volumes to 2 cu. ft.

All furnaces have fully automatic program and control functions to meet the most exacting time-temperature cycles.

GLASS TESTING

Softening point (per ASTM C-336) and strain/annealing point (per ASTM C-338) are determined for customer supplied glass fibers. Also available are softening point determinations using patented Harrop/Labino method. See Harrop Bulletin #61.

GRADIENT FURNACE

Designed by Harrop for studying the behavior of materials as a function of temperature and atmosphere. Specimens are heated in a tube furnace which subjects the material to a known, adjustable temperature gradient. Accurate temperature monitoring along the sample length permits exact identification of thermal processing at any point.

The furnace design provides for controlled, dynamic atmospheres. Materials can be fired or heated over a broad temperature range (1600°C maximum) in one operation, eliminating time-consuming multiple firings. Powder, pellet, or continuous bar test specimens can be handled.

Typical applications include color studies, density-porosity relationships, glaze fit, phase development and maturing range investigations.

HOT LOAD/CREEP TESTING

Load testing of refractory brick at high temperature to find long-term deformation per ASTM C-546 (Max. load 400 lbs.)

HARROP INDUSTRIES, INC.
MATERIALS EVALUATION SECTION
3470 East Fifth Avenue
Columbus, Ohio 43219-1797
Phone: 614/231-3621
TELEX II 810-482-1645

CLAY TESTING

In addition to the thermal analysis techniques used to characterize clays, Harrop has facilities available to grind, screen, mix, extrude, and press clay or clay-containing bodies. Observation during these processes with subsequent drying, burnout, and maturing studies pinpoint areas of interest or potential problems.

The testing services is useful in new deposit or feasibility analysis, composition development or modification, and troubleshooting. Kiln profile modification is an area where the clay testing is very useful. Using combinations of body modification and burnout removal analysis, total kiln cycle times have been decreased 15 to 25%.

For details on how to use Harrop's facilities most effectively, a discussion with our laboratory personnel will be helpful.

DRIP SLAG TESTING

Determination of refractory brick resistance to molten slag dripped continuously onto the test specimens at high temperature per ASTM C-768.

HARROP

the mark of knowledge in the application of heat

Specifications subject to change without notice.

MES 283 2.5K

Printed in U.S.A.

TABLE XXIC

BURNER PERFORMANCE DATA

TABLE I COMBUSTION AIR CAPACITIES in CFH
(Not Including Atomizing Air)

Burner Designation	Air Pressure at Burner in osi											
	0.432	1.730	3.460	5.189	6.919	8.649	10.379	13.383	17.298	20.758	24.217	27.677
	0.25	1	2	3	4	5	6	8	10	12	14	16
225-2	250	500	700	860	1000	1120	1220	1400	1570	1720	1860	2000
225-4	725	1450	2040	2510	2900	3250	3540	4080	4570	5020	5420	5800
225-6	1625	3250	4580	5620	6500	7280	7930	9160	10280	11240	12120	13000

For Burner Capacities in Btu per hour, multiply above figures by 100.

Btu capacities in Table 1 are based on 100% air for combustion through the burner when operating on gas with the shutter closed. Combustion air should not exceed 16 osi pressure at the burner. When operating on oil with the shutter closed, Btu capacities may be increased at least 20% because of the additional air supplied through the burner for atomization. For either gas or oil operation, Btu capacities may be doubled with the shutter open, provided furnace conditions assure sufficient secondary air. In actual practice, few furnaces do supply sufficient secondary air to double Btu capacities.

TABLE II FACTORS for DETERMINING REQUIRED GAS PRESSURES

Multiply the air pressure at the burner by the appropriate factor listed below to find a gas pressure at the burner sufficient for all burner operating conditions.

Gas	1000 Btu 0.6 Sp Gr	800 Btu 0.6 Sp Gr	500 Btu 0.6 Sp Gr	500 Btu 0.4 Sp Gr	2500 Btu 1.55 Sp Gr	3200 Btu 1.95 Sp Gr
Factor	0	0.03	0.22	0.13	0	0

TABLE III ATOMIZING AIR CAPACITIES in CFH

Burner Designation	Air Pressure at Burner in osi					
	14	16	18	20	22	24
225-2	840	900	955	1010	1050	1100
225-4	1660	1780	1890	1995	2085	2175
225-6	3920	4200	4450	4700	4920	5130

SIZING OF BLOWERS

Blowers picked must be capable of delivering the necessary volume of air at the required pressure. If a single blower is used to supply both combustion and atomizing air, it must develop the higher pressures required for atomizing air. Find the required volume of air in cfh by adding the atomizing air capacity from Table 3 to the combustion air capacity from Table 1. For example, to select a blower for a 225-4 Burner operating with 16 osi combustion air and 22 osi atomizing air, at the burner, go to Table 1 to get 5800 cfh of combustion air, and to Table 3 to get 2085 cfh of atomizing air. This adds up to a total of 7885 cfh of air required. North American Blower 324-B3-2 meets the requirements, delivering 9000 cfh at 24 osi.

TURNDOWN

Series 225 Burners have a turndown of 4 to 1. The urndown is somewhat higher when operating on gas with the shutter open, going as high as 8 to 1 if the furnace supplies sufficient secondary air to double the burner's capacity. Burners may be run on atomizing air only (combustion air shut off) when operating on either light or heavy oil, but in this case they must be run somewhat rich if the furnace is cold.

Form No. M1153 - B225 - 10M

rinted in U. S. A.

TABLE I. Air Capacities, cfh, with 16 osi at the burner inlet.

Burner Designation	When burning on stoichiometric (10:1) air/gas ratio	When not burning (use this to size the blower)
4442-2	2,330	3,000
4442-3	3,540	4,190
4442-4	5,800	6,480
4442-5	9,480	11,500
4442-6	14,900	18,200
4442-7	22,200	24,600

24 osi

4442-3 3,990 4600

TABLE II. Air & Gas Capacities vs. Air & Gas Orifice Pressure Drops.

Pressure Drop across air orifice, "wc (UA minus DA) ①	AIR FLOW, cfh, (70 F, 29.9" Hg) 4442-2	4442-3	4442-4	4442-5
0.3	400	525	850	1,590
1.5	895	1170	1890	3,570
3.0	1270	1665	2670	5,050
4.5	1555	2030	3270	6,150
6.0	1795	2340	3770	7,140
7.5	2010	2620	4220	7,960
9.0	2200	2870	4620	8,720
10.5	2380	3100	4990	9,420
12.0	2540	3310	5340	10,100
13.5	2690	3520	5670	10,700
15.0	2840	3700	5960	11,250

Pressure Drop across gas orifice, "wc (UG minus DG) ①	NATURAL GAS (0.6 sp gr) flow, cfh 4442-2	4442-3	4442-4	4442-5
0.1	40	53	85	159
0.5	90	117	189	357
1.0	127	167	267	505
1.5	156	203	327	615
2.0	180	234	377	714
2.5	201	262	422	796
3.0	220	287	462	872
3.5	238	310	499	942
4.0	254	331	534	1010
4.5	269	352	567	1070
5.0	284	370	596	1125

4442-6 Air & Natural Gas Capacities

ΔP across air orifice, "wc (UA - DA) ①	AIR flow, cfh	ΔP across gas orifice, "wc (UG - DG) ①	GAS flow, cfh
0.3	3,570	0.3	357
1.5	7,950	1.5	795
3.0	11,300	3.0	1130
4.5	13,800	4.5	1380
6.0	16,000	6.1	1600
7.5	17,900	7.6	1790
9.0	19,600	9.1	1960

4442-7 Air & Natural Gas Capacities

ΔP across air orifice, "wc (UA - DA) ①②	AIR flow, cfh	ΔP across gas orifice, "wc (UG - DG) ①	GAS flow, cfh
0.3	7,000	0.4	700
0.5	9,050	0.7	905
1.0	12,800	1.4	1280
1.5	15,700	2.2	1570
2.0	18,100	2.9	1810
3.0	22,200	4.3	2220
4.5	25,600	5.7	2560

To obtain propane pressure drop for same Btu/hr input, multiply natural gas pressure drop by 0.4.

① See dimension drawing. ② Air orifice optional with 4442-7.

TABLE III. Natural Gas Pressure Drop Factors. (Multiply burner air orifice pressure drop by appropriate factor below to obtain gas orifice pressure drop for desired excess air rate.)

Desired % xsair	4442-2 thru -5	4442-6	4442-7
0 (stoichiometric)	.33	1.12	1.43
10	.28	.93	1.18
20	.23	.78	1.00
30	.20	.66	.85
40	.17	.57	.73
50	.15	.50	.64
100	.083	.28	.36
150	.053	.18	.23
200	.038	.12	.16
300	.021	.070	.090
400	.013	.045	.057
500	.009	.031	.040
600	.007	.023	.029
700	.005	.018	.022
800	.004	.014	.018
1000	.003	.009	.012

APPENDIX D - CALCULATIONS

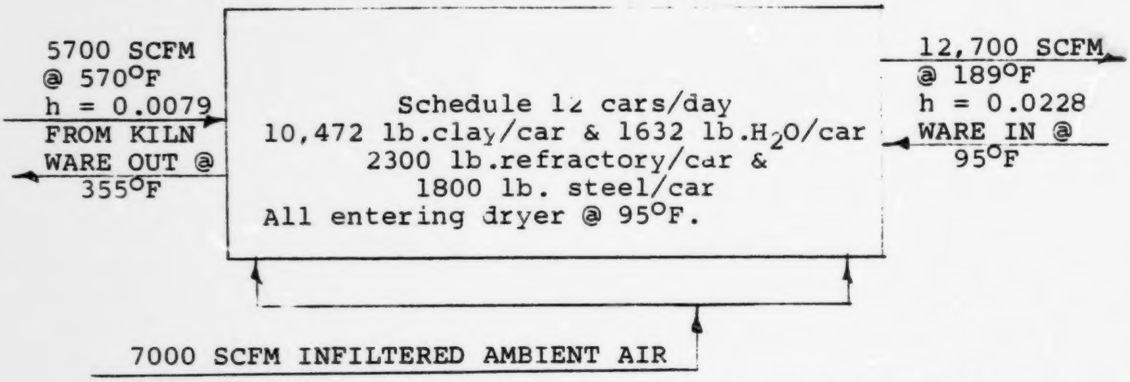
Notation

G	weight of hot air from kiln to dryer, lb./day
Gx	weight of infiltered ambient air to dryer, lb./day
Wc	mass flow rate of clay, lb./car
Ww	mass flow rate of water, lb./car
Wr	mass flow rate of refractories dead load, lb./car
Ws	mass flow rate of steel dead load, lb./car
N	car schedule, cars/day,
T1	ambient temperature, ^{o}F, i.e. 70^{o}F
T2	temperature of air entering dryer, ^{o}F
T3	temperature of air leaving dryer, ^{o}F
T4	temperature of materials entering dryer, ^{o}F
T5	temperature of materials leaving dryer, ^{o}F
Cc	specific heat of clay, Btu/lb./^{o}F, i.e. 0.22
Cr	specific heat of ware and refractory, Btu/lb./^{o}F,i.e.0.22
C	specific heat of steel, Btu/lb./^{o}F, i.e. 0.11
Ls	surface heat losses, Btu/day
Lc	chimney heat loss, Btu/day
H1	enthalpy of ambient air, Btu/lb.
H2	enthalpy of hot air entering dryer, Btu/lb.
H3	enthalpy of hot air leaving dryer, Btu./lb.
T6	temperature of hot air entering dryer, ^{o}F
H6	enthalpy of hot air entering dryer, Btu/lb.
Ld	heat loss in 36" O.D. duct from kiln to dryer, Btu/day
h	humidity ratio, lb. water vapour/lb. dry air
Hv	enthalpy water vapour
ΔH	heat of vapourization of water in dryer, Btu/lb.
T7	temperature of hot air leaving kiln, ^{o}F
H7	enthalpy of hot air leaving kiln, Btu/lb.
Ld	heat loss in hot air supply duct, Btu/day

Dryer Energy and Material Balances for Acid Brick

A. Energy Balance

Ambient Air D.B. = 80°F, W.B. = 62°F, h = 0.0079
Entering air temp. 590°F - 20°F = 570°F
SCFM at a temp. of 32°F



All energy inputs and outputs referred to a temperature datum of 80°F, i.e. ambient temperature.

1. Heat Input

a. Hot air heat input to dryer:

$$= G\ (H_2 - H_1)$$

$G = 5700 \times 1440 \times 0.0808 = 663{,}200$ lb./day
$H_1 = (0.24 \times 80) + (0.0079 \times 1097) = 27.9$ Btu/lb.
$H_2 = (0.24 \times 570) + (0.0079 \times 1322) = 147.2$ Btu/lb.

$G = 663{,}200\ (147.2 - 27.9)$
$G = 79{,}120{,}000$ Btu/day

b. Heat input by ware and car deck refractory:

$= (Wc + Wr) \times 0.22 \times 12 \times (95 - 80)$
$= (10{,}472 + 2300) \times 0.22 \times 12 \times 15 = 505{,}000$ Btu/day

c. Heat input by water in ware:

$= Ww \times 12 \times 1.0 \times (95 - 80)$
$= 1632 \times 12 \times 1.0 \times 15$
$= 294{,}000$ Btu/day

d. Heat input by car steel:

= Ws x 12 x 0.11 x (95 - 80)
= 59,000 Btu/day

e. Total heat input:

70,120,000
550,000
294,000
59,000

= 79,978,000 Btu/day

2. Kiln-to-Dryer Transport Heat Loss

Air leaves kiln at 740°F. Gross input to dryer:

$= G\ (H_6 - H_1)$
$H_6 = (0.24 \times 740) + (0.0079 \times 1404) = 188.7$ Btu/lb.

$G(H_6 - H_1) = 663{,}200\ (188.7 - 27.9)$
$= 106{,}642{,}000$ Btu/day

$\therefore$ heat loss in 36" dia. duct is:
Ld = 106,642,000 - 79,978,000 = 26,664,000 Btu/day

3. Heat Output and Losses

a. Heat to ware and car deck refractory:

= (Wc + Wr) x 0.22 x 12 x (355 - 95)
= (10,472 + 2300) x 0.22 x 12 x 260
= 8,767,000 Btu/day

b. Heat to raise water temperature to 189°F:

= Ww x 12 x 1.0 x (189-95)
= 1632 x 12 x 1.0 x 94
= 1,841,000 Btu/day

c. Heat to evaporate water at 189°F:

= Ww x 12 x 997
= 1632 x 12 x 997
= 19,525,000 Btu/day

d. Heat to raise temp. of car steel:

= Ws x 12 x 0.11 x (355 - 95)
= 1800 x 12 x 0.11 x 260
= 618,000 Btu/day

e. Heat lost in exhaust air (includes heat to raise temperature of 7000 scfm of infiltered air to 189°F):

$$= G + Gx\ (H3 - H1)$$

$H_3 = (189 \times 0.24) + (0.0079 \times 1142) = 54.4$ Btu/lb.

$G + Gx\ (H_3 - H_1) = 12{,}700 \times 1440 \times 0.0808\ (54.4 - 27.9)$
$= 39{,}158{,}000$ Btu/day

Heat loss by infiltered air alone $= 7000/12{,}700 \times 39{,}158{,}000$
$= 21{,}583{,}000$ Btu/day

f. Heat losses from dryer surfaces, L_s:

L_s = (Brick surface area)(Combined convection and radiation coefficient for brick)(Temp. difference between brick and still air)(24 hr./day)

+

(Steel surface area of fans and ducts)(Combined convection and radiation coefficient for steel)(Temp. difference between steel and still air)(29 hr./day)

Estimated brick surface area = 2800 ft.^{2} (assuming no heat loss from first 50 ft. of dryer length)

Estimated steel surface area = 660 ft.^{2}

Temperature of brick surface = 140°F (measured at middle of dryer)

Average surface temperature of steel surfaces = 220°F

Obtain coefficients from pages 377 to 378, Mark's Handbook, 5th ed.

$L_s = 2800(1.40 \times 65)\ 24 + 660(2.50 \times 140)\ 24$
$= 6{,}115{,}000 + 5{,}544{,}000$
$= 11{,}659{,}000$ Btu/day

g. Total heat output and losses:

8,767,000
1,841,000
19,525,000
618,000
39,158,000
11,659,000

= 81,568,000 Btu/day

Difference:

Input - (output + losses) = 79,978,000 - 81,568,000
+ -1,590,000 Btu/day

Note: See summary table on following page.

B. Material Balance on Water

Ware leaves dryer with all mechanically bound water removed.

∴ water evaporate from ware = 1632 x 12 = 19,580 lb./day

Water removed by kiln hot air and infiltrated air:

$$= (G + Gx) \times (h_o - H_i)$$
$$= (12{,}700 \times 1440 \times 0.0808) \times (0.0228 - 0.0079)$$
$$= 22{,}020 \text{ lb./day}$$

Difference is:

22,020 - 19,580 = 2,440 lb./day

Calculate thermal efficiency using,

$$N = \frac{100\ (T_1 - T_2)}{T_1 - T_a}$$

$$= \frac{100\ (570 - 450)}{570 - 80}$$

$$= 24.5\% \qquad \text{(Checks)}$$

Evaporative efficiency, N_e

$$N_e = \frac{100\ (T_1 - T_2)}{T_1 - T_s}$$

$$= \frac{100\ (570 - 450)}{570 - 124}$$

$$= 26.9\%$$

Summary-Dryer Energy Balance

Item	Input x 1000 Btu/day	Output & Losses x 1000 Btu/day	%
Provision by hot air from kiln	79,120	-	
Ware and car deck refractory and steel in car	564	9,385	11.5
Water in ware	294	1,841	2.3
Evaporation of water	-	19,525	23.9
Exhaust air	-	39,158(1)	48.0
Surface heat losses	-	11,659	14.3
Unaccounted	1,590		
Totals	81,568	81,568	100.0

(1) Includes 21,583,000 Btu/day heat loss due to infiltered air.

C. Dryer Thermal Efficiency

$$= \frac{\text{Heat required to evaporate water} \times 100\%}{\text{Total heat input}}$$

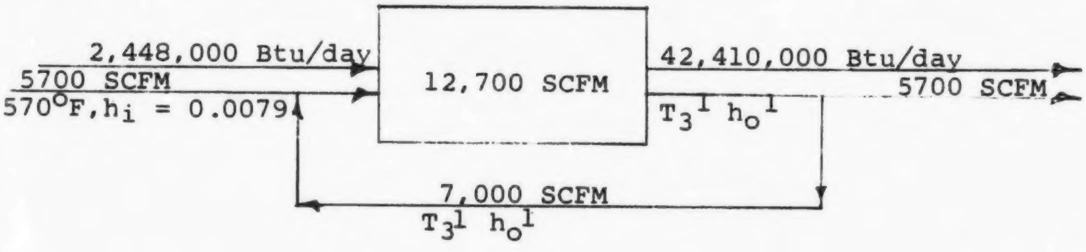
$$= \frac{19,525,000}{81,568,000} \quad \times \quad 100\%$$

$$= 23.9\%$$

D. Air Recirculation

Air recirculation would have the effect of increasing exhaust air temperature and humidity. Subsequently, the amount of heat supplied to the dryer may be decreased, thus increasing dryer efficiency. A bigger dryer would not be required if the amount of recirculated air is not substantially greater than that now being infiltered. Infiltered air appears to lower air temperature and humidity in the first three sections of the dryer as shown on the chart on the preceding page (effects occur by dilution). A portion of the exhaust air should be recirculated to the 3rd or 4th section.

Recirculate 7000 scfm and estimate resulting exhaust air temperature and humidity.



Assume all heat input and output values for solids and water and surface heat losses remain the same for purposes of this estimate.

Recycle ration, $R = h_o^1 - h_o/h_o^1 - h_i$

or $h_o^1 = Rh_i - h_o/R - 1$

where h_o^1 is the new exhaust humidity
$R = 7000/12{,}700 = 0.551$, $h_i = 0.0079$, $h_o = 0.0228$

$$h_o^1 = 0.551 \times 0.0079 - 0.0228/0.551 - 1$$
$$= 0.0185/0.449$$
$$= 0.0412$$

5,700 scfm = 663,200 lb./day
7,000 scfm = 814,500 lb./day

Let T_3^1 and H_3^1 be new outlet temperature and enthalpy.

Write energy balance,

$$663{,}200\ (H_2 - H_1) + 814{,}500\ (H_3^1 - H_1) + 2{,}448{,}000 =$$
$$663{,}200\ (H_3^1 - H_1) + 814{,}500\ (H_3^1 - H_1) + 42{,}410{,}000$$

which reduces to

$$663{,}200(H_2 - H_1) = 663{,}200(H_3{}^1 - H_1) + 39{,}962{,}000$$

$$H_2 - H_3{}^1 = 60.26$$

$H_2 = 147.2$

Then $H_3{}^1 = 87.0$ Btu/lb.

Write new enthalpy equation assuming $T_3{}^1 = 300^oF$

$$0.24\ T_3{}^1 + 0.0079 \times 1193 = 87.0$$

$$0.24\ T_3{}^1 = 77.57$$

$$T_3{}^1 = 323^oF$$

Since T_3 is 189^oF, the increase in exhaust temp. would be about 134^oF.

By replacing infiltered air with recirculated exhaust air the 21,583,000 Btu/day previously used to heat infiltered air would be saved. For the same load, heat input to the dryer may be decreased for a further saving.

E. Reduce Exhaust Fan Output & Exclude Infiltered Air

Air in = air out = 5700 scfm.

Let $H_3{}^{11}$ be enthalphy of exit air, then

$$663{,}200\ (H_2 - H_3{}^{11}) - 81{,}568{,}000 - 39{,}158{,}000$$

$$H_2 - H_3{}^{11}) - 63.94$$

$H_2 = 147.2$, then

$$H_3{}^{11} \simeq 83.3$$

$$0.24\ T_3{}^{11} + (0.0079 \times 1150) - 83.3$$

$$T_3{}^{11} \simeq 309^oF$$

Humidity ratio would be 12,700/5700 x 0.0228 = 0.0508

G. Insulation of 36" Dia. Duct-Kiln to Dryer

A manufacturer's analysis of heat loss for the 36" dia. duct follows.

Heat loss calculated from measured data for the 300 ft. long 36" dia. duct was 26,664,000 Btu/day which is

$$26{,}664{,}000/24 \times 300 = 3703 \text{ Btu/hr. ft.}$$

The duct is insulated with about 1" thk fiberglass. Hot air enters duct at 740°F and leaves at 520°F.

Manufacturer's data for 1" thk fiberglass shows a heat loss of 3452 Btu/hr. ft. at 740°F (244.5°F surface temp.) and 148.60 Btu/hr. ft. at 520°F (147.3°F surface temp.). Average heat loss would then be that occurring at an average surface temperature of 244.5 + 147.3/2 = 196°F which estimated from the manufacturer's data by interpolation is

$$186.73 + (3452.79 - 1862.73) \times \left(\frac{196.0 - 176.8}{244.5 - 176.8}\right)$$

$$= 1862.73 + (1590.06) \times \left(\frac{19.2}{67.7}\right)$$

$$= 1862.73 + 450.95$$

$$= 2313.68 \text{ Btu/hr. ft.}$$

The heat loss of 2313.68 Btu/hr. ft. indicates the heat loss that may be expected with modern 1" thk fiberglass enclosed in an aluminum jacket.

Since the existing 36" duct already has an insulation value approximately equal to 1" thk insulation shown on page 1 for system A, annual cost savings should be reference to 1" thickness rather than bare pipe. Using data from page 1, the following simple payback evaluation may be made.

9/30/85
Orig + 2 - G. Liseth
cc. file

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                    JOHNS-MANVILLE
             ENERGY REDUCTION ANALYSIS
               FOR HOT SURFACES(ETIH)
               NEW AND RETROFIT JOBS


PROJECT-       CLAYBURNE 36" PIPE  PROJECT NO-        (1) ERA85-080-17
SYSTEM -                        A  LOCATION  -        ABBOTSFORD, B.C.
DATE   -          SEPT. 29, 1985  ENGINEER  -              ?C.D. KENT
CONTACT-             G.N. LISETH


FUEL TYPE     - STEAM
PRESENT PRICE-      4.0  $/MMBTU
EFFICIENCY    - 100.00 PERCENT

ANNUAL FUEL INFLATION RATE                       -  10.0 PERCENT
AFTER TAX VALUE OF MONEY                         -  15.0 PERCENT
INCREMENTAL HEATING EQUIPMENT INVESTMENT         -   2.00 $/1000 BTU/HR
EFFECTIVE INCOME TAX RATE                        -  46.0 PERCENT
HEATING PLANT DEPRECIATION PERIOD                -  20.0 YRS
ECONOMIC LIFE OF NEW INSULATION                  -  20.0 YRS
EMISSIVITY OF JACKETING                          -   0.20
PERCENT OF NEW INSULATION COST
        FOR ANNUAL INSULATION MAINTAINENCE -     1.0 PERCENTPER YEAR
PERCENT OF ANNUAL FUEL BILL
        FOR HEATING PLANT MAINTAINENCE           -   5.0 PERCENT PERYEAR
ANNUAL AVERAGE WIND SPEED                        -   5.00 MPH
EMISSIVITY OF PRESENT SURFACE                    -   0.90
CALCULATIONS PERFORMED USING DISCRETE COST AND THICKNESS DATA



POSSIBLE ERROR MESSAGES
(MESSAGE SYMBOLS APPEAR AT BEGINNING OF EACH LINE OF OUTPUT)

*--PROCESS TEMPERATURE IS ABOVE MAXIMUM ALLOWED FOR THE CALCULATION OF
   THERMAL CONDUCTIVITY OF FIRST LAYER,  CALCULATIONS WERE PERFORMED, BUT
   RESULTS MAY BE QUESTIONABLE.

$--STATED ETI IS AT UPPER LIMIT OF THICKNESS DATA AND MAY NOT BE TRUE ETI.

=--INTERFACE TEMPERATURE BETWEEN OLD INSULATION AND NEW INSULATION IS ABOVE
   THE ALLOWABLE MAXIMUM FOR THE NEW INSULATION.  CALCULATIONS WERE
   PERFORMED, BUT RESULTS MAY BE QUESTIONABLE.
```

```
                                                       SURFACE  1 OF  2
                                                       Acid [illegible]

   PIPE OR SURFACE DESCRIPTION              -  36.00
                                                     INCH IPS-HORIZONTAL PIPE
   OPERATING TEMPERATURE                    -   740.0 F
   AMBIENT TEMPERATURE                      -    80.0 F
   PREVIOUS INSULATION                      -          NONE      (CODE  TYPE  0)
   NEW INSULATION                           -     FIBERGLASS     (CODE TYPE   5)
   PREVIOUS THICKNESS OF INSULATION         -   0.00 IN.
   HOURS OF OPERATION                       -  8760.0  PER YEAR
   REFERENCE THICKNESS OF INSULATION
                 FOR PAYBACK CALCULATION - 0.00 IN.
   PIPING COMPLEXITY FACTOR                 -  1.15
   CONDUCTIVITIES SUPPLIED BY USER    NEW - NONE SUPPLIED
                                      OLD - NONE SUPPLIED


 THICK.                         PRES. VALUE
 OF NEW  ANNUAL   PAYBACK       OF HEAT         HEAT         SURF.   INSUL.
 INSUL.   COST    PERIOD         SAVED          LOSS         TEMP.    COST
  (IN)   ($/FT)    (YRS)        ($/FT)      (BTU/HR-FT)       (F)    ($/FT)

   0.00  1753.76    ****          0.00      42361.72        727.5      0.00
 * 1.00   153.04               1031.73         3452.79        244.5     68.22
 * 2.00    88.60               1073.89         1862.73        176.8     77.61
 * 3.00    67.43               1088.98         1293.62        149.5     93.78
 * 4.00    56.83               1096.73         1001.38        134.5    103.90
   5.00    51.02               1101.43          824.05        124.9    114.30
*$ 6.00    47.75               1104.61          704.13        118.2    125.72

   ***************************************************************************
   *                                                                         *
   *  ETI CORRESPONDS TO THE THICKNESS WITH THE LOWEST ANNUAL COST:   6.00IN *
   *                                                                         *
   ***************************************************************************



   HEAT SAVINGS AND PRESENT VALUES ARE PROJECTED ON GIVEN INPUT VARIABLES.
   ACTUAL VALUES MAY VARY DEPENDING ON THE ACTUAL SERVICE CONDITIONS.
```

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                                                       SURFACE  2 OF  2
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[illegible]

```
PIPE OR SURFACE DESCRIPTION              -   VERTICAL FLAT SURFACE
OPERATING TEMPERATURE                    -   520.0 F
AMBIENT TEMPERATURE                      -    80.0 F
PREVIOUS INSULATION                      -         NONE      (CODE  TYPE  0)
NEW INSULATION                           -     FIBERGLASS    (CODE TYPE   3)
PREVIOUS THICKNESS OF INSULATION         -   0.00 IN.
HOURS OF OPERATION                       -  8760.0  PER YEAR
REFERENCE THICKNESS OF INSULATION
             FOR PAYBACK CALCULATION - 0.00 IN.
PIPING COMPLEXITY FACTOR                 -  1.15
CONDUCTIVITIES SUPPLIED BY USER    NEW - NONE SUPPLIED
                                   OLD - NONE SUPPLIED

THICK.                           PRES. VALUE
OF NEW   ANNUAL    PAYBACK        OF HEAT          HEAT          SURF.    INSUL.
INSUL.    COST     PERIOD          SAVED           LOSS          TEMP.     COST
 (IN)  ($/SQ-FT)   (YRS)        ($/SQ-FT)   (BTU/HR-SQ-FT)     (F)   ($/SQ-FT)

  0.00    109.01     ****            0.00         2633.14       520.0      0.00
  1.00      7.14     0.04           65.88          148.60       147.3      6.69
  2.00      4.27     0.04           67.77           77.35       119.8      7.22
  3.00      3.26     0.04           68.43           52.36       109.1      7.41
  4.00      2.82     0.06           68.77           39.55       103.2      7.98
  5.00      2.64     0.07           68.98           31.79        99.4      8.97
  6.00      2.56     0.09           69.12           26.58        96.8      9.89
  7.00      2.60     0.12           69.22           22.84        94.8     11.21

 ***********************************************************************************
 *                                                                                 *
 *  ETI CORRESPONDS TO THE THICKNESS WITH THE LOWEST ANNUAL COST:       6.00IN *
 *                                                                                 *
 ***********************************************************************************


 HEAT SAVINGS AND PRESENT VALUES ARE PROJECTED ON GIVEN INPUT VARIABLES.
 ACTUAL VALUES MAY VARY DEPENDING ON THE ACTUAL SERVICE CONDITIONS.
```

9/30/85
orig+2 - G. Liseth
cc - file

```
                    JOHNS-MANVILLE
               ENERGY REDUCTION ANALYSIS
                FOR HOT SURFACES(ETIH)
                NEW AND RETROFIT JOBS


PROJECT-    CLAYBURNE FANS & DUCT  PROJECT NO-          (2) ERA85-080-15
SYSTEM -                        B  LOCATION  -          ABBOTSFORD, B.C.
DATE   -          SEPT. 29, 1985  ENGINEER  -                 ?C.D. KENT
CONTACT-              G.N. LISETH


FUEL TYPE     - STEAM
PRESENT PRICE-       4.0  $/MMBTU
EFFICIENCY    - 100.00 PERCENT

ANNUAL FUEL INFLATION RATE                -  10.0 PERCENT
AFTER TAX VALUE OF MONEY                  -  15.0 PERCENT
INCREMENTAL HEATING EQUIPMENT INVESTMENT  -   2.00 $/1000 BTU/HR
EFFECTIVE INCOME TAX RATE                 -  46.0 PERCENT
HEATING PLANT DEPRECIATION PERIOD         -  20.0 YRS
ECONOMIC LIFE OF NEW INSULATION           -  20.0 YRS
EMISSIVITY OF JACKETING                   -   0.20
PERCENT OF NEW INSULATION COST
        FOR ANNUAL INSULATION MAINTAINENCE -   1.0 PERCENTPER YEAR
PERCENT OF ANNUAL FUEL BILL
        FOR HEATING PLANT MAINTAINENCE     -   5.0 PERCENT PERYEAR
ANNUAL AVERAGE WIND SPEED                 -   5.00 MPH
EMISSIVITY OF PRESENT SURFACE             -   0.90
CALCULATIONS PERFORMED USING DISCRETE COST AND THICKNESS DATA


POSSIBLE ERROR MESSAGES
(MESSAGE SYMBOLS APPEAR AT BEGINNING OF EACH LINE OF OUTPUT)

*--PROCESS TEMPERATURE IS ABOVE MAXIMUM ALLOWED FOR THE CALCULATION OF
   THERMAL CONDUCTIVITY OF FIRST LAYER,  CALCULATIONS WERE PERFORMED, BUT
   RESULTS MAY BE QUESTIONABLE.

$--STATED ETI IS AT UPPER LIMIT OF THICKNESS DATA AND MAY NOT BE TRUE ETI.

=--INTERFACE TEMPERATURE BETWEEN OLD INSULATION AND NEW INSULATION IS ABOV
   THE ALLOWABLE MAXIMUM FOR THE NEW INSULATION.  CALCULATIONS WERE
   PERFORMED, BUT RESULTS MAY BE QUESTIONABLE.
```

```
                                                       SURFACE  1 OF  6

   PIPE OR SURFACE DESCRIPTION                  -   VERTICAL FLAT SURFACE WHF
   OPERATING TEMPERATURE                        -   401.0 F            (Supply Fan)
   AMBIENT TEMPERATURE                          -    80.0 F
   PREVIOUS INSULATION                          -
   NEW INSULATION                               -             NONE     (CODE  TYPE  0)
   PREVIOUS THICKNESS OF INSULATION             -      FIBERGLASS      (CODE TYPE   3)
   HOURS OF OPERATION                           -   0.00 IN.
   REFERENCE THICKNESS OF INSULATION            -  8760.0  PER YEAR
                  FOR PAYBACK CALCULATION - 0.00 IN.
   PIPING COMPLEXITY FACTOR                     -   1.15
   CONDUCTIVITIES SUPPLIED BY USER   NEW - NONE SUPPLIED
                                     OLD - NONE SUPPLIED

 THICK.
 OF NEW  ANNUAL    PAYBACK   PRES. VALUE
 INSUL.   COST     PERIOD     OF HEAT        HEAT        SURF.   INSUL.
  (IN)  ($/SQ-FT)  (YRS)      SAVED          LOSS        TEMP.    COST
                            ($/SQ-FT)   (BTU/HR-SQ-FT)   (F)   ($/SQ-FT)

  0.00    67.48     ****        0.00        1629.88      401.0     0.00
  1.00     4.87     0.12       40.73          93.69      126.5     6.69
  2.00     3.10     0.13       41.92          49.02      107.6     7.22
  3.00     2.47     0.14       42.34          33.24      100.1     7.41
  4.00     2.22     0.15       42.55          25.15       96.1     7.98
  5.00     2.16     0.18       42.68          20.23       93.5     8.97
  6.00     2.16     0.21       42.77          16.92       91.6     9.89
  7.00     2.26     0.25       42.83          14.55       90.3    11.21

 *************************************************************************
 *                                                                       *
 *  ETI CORRESPONDS TO THE THICKNESS WITH THE LOWEST ANNUAL COST:  6.00IN *
 *                                                                       *
 *************************************************************************


 HEAT SAVINGS AND PRESENT VALUES ARE PROJECTED ON GIVEN INPUT VARIABLES.
 ACTUAL VALUES MAY VARY DEPENDING ON THE ACTUAL SERVICE CONDITIONS.
```

```
                                                        SURFACE  2 OF  6

PIPE OR SURFACE DESCRIPTION                 -   VERTICAL FLAT SURFACE  RF No. 4
OPERATING TEMPERATURE                       -   311.0 F
AMBIENT TEMPERATURE                         -    80.0 F
PREVIOUS INSULATION                         -          NONE      (CODE  TYPE  0)
NEW INSULATION                              -       FIBERGLASS   (CODE TYPE   3)
PREVIOUS THICKNESS OF INSULATION            -    0.00 IN.
HOURS OF OPERATION                          -  8760.0  PER YEAR
REFERENCE THICKNESS OF INSULATION
                     FOR PAYBACK CALCULATION - 0.00 IN.
PIPING COMPLEXITY FACTOR                    -  1.15
CONDUCTIVITIES SUPPLIED BY USER      NEW - NONE SUPPLIED
                                     OLD - NONE SUPPLIED


THICK.                          PRES. VALUE
OF NEW   ANNUAL     PAYBACK     OF HEAT          HEAT          SURF.    INSUL.
INSUL.    COST      PERIOD       SAVED           LOSS          TEMP.     COST
 (IN)   ($/SQ-FT)   (YRS)      ($/SQ-FT)   (BTU/HR-SQ-FT)     (F)   ($/SQ-FT)

 0.00     42.37      ****          0.00         1023.36       311.0      0.00
 1.00      3.49      0.26         25.54           60.30       112.6      6.69
 2.00      2.38      0.27         26.29           31.73        99.4      7.22
 3.00      1.99      0.28         26.57           21.53        94.1      7.41
 4.00      1.86      0.31         26.70           16.30        91.3      7.98
 5.00      1.87      0.36         26.79           13.12        89.5      8.97

*****************************************************************************
*                                                                           *
*  ETI CORRESPONDS TO THE THICKNESS WITH THE LOWEST ANNUAL COST:     4.00IN
*                                                                           *
*****************************************************************************


HEAT SAVINGS AND PRESENT VALUES ARE PROJECTED ON GIVEN INPUT VARIABLES.
ACTUAL VALUES MAY VARY DEPENDING ON THE ACTUAL SERVICE CONDITIONS.
```

```
                                                            SURFACE  3 OF  6

PIPE OR SURFACE DESCRIPTION                  -  VERTICAL FLAT SURFACE RF No 5
OPERATING TEMPERATURE                        -  257.0 F
AMBIENT TEMPERATURE                          -   80.0 F
PREVIOUS INSULATION                          -          NONE     (CODE  TYPE  0)
NEW INSULATION                               -       FIBERGLASS  (CODE TYPE   3)
PREVIOUS THICKNESS OF INSULATION             -  0.00 IN.
HOURS OF OPERATION                           - 8760.0  PER YEAR
REFERENCE THICKNESS OF INSULATION
                    FOR PAYBACK CALCULATION - 0.00 IN.
PIPING COMPLEXITY FACTOR                     -  1.15
CONDUCTIVITIES SUPPLIED BY USER         NEW - NONE SUPPLIED
                                        OLD - NONE SUPPLIED

THICK.
OF NEW   ANNUAL    PAYBACK   PRES. VALUE
INSUL.    COST     PERIOD     OF HEAT        HEAT        SURF.    INSUL.
 (IN)  ($/SQ-FT)   (YRS)       SAVED         LOSS        TEMP.     COST
                             ($/SQ-FT)  (BTU/HR-SQ-FT)   (F)    ($/SQ-FT)

 0.00    29.60      ****        0.00        714.89       257.0      0.00
 1.00     2.78      0.41       17.81         43.16       104.9      6.69
 2.00     2.01      0.44       18.35         22.77        94.8      7.22
 3.00     1.74      0.44       18.55         15.47        90.8      7.41
 4.00     1.67      0.48       18.65         11.73        88.6      7.98
 5.00     1.72      0.55       18.71          9.45        87.2      8.97

*****************************************************************************
*
*  ETI CORRESPONDS TO THE THICKNESS WITH THE LOWEST ANNUAL COST:     4.00IN
*
*****************************************************************************


HEAT SAVINGS AND PRESENT VALUES ARE PROJECTED ON GIVEN INPUT VARIABLES.
ACTUAL VALUES MAY VARY DEPENDING ON THE ACTUAL SERVICE CONDITIONS.
```

```
                                                      SURFACE  4 OF  6

    PIPE OR SURFACE DESCRIPTION              -   VERTICAL FLAT SURFACE RFN. 2
    OPERATING TEMPERATURE                    -   248.0 F
    AMBIENT TEMPERATURE                      -    80.0 F
    PREVIOUS INSULATION                      -           NONE      (CODE  TYPE  0)
    NEW INSULATION                           -     FIBERGLASS      (CODE TYPE   3)
    PREVIOUS THICKNESS OF INSULATION         -   0.00 IN.
    HOURS OF OPERATION                       -  8760.0  PER YEAR
    REFERENCE THICKNESS OF INSULATION
                  FOR PAYBACK CALCULATION - 0.00 IN.
    PIPING COMPLEXITY FACTOR                 -  1.15
    CONDUCTIVITIES SUPPLIED BY USER   NEW - NONE SUPPLIED
                                      OLD - NONE SUPPLIED


  THICK.                          PRES. VALUE
  OF NEW   ANNUAL    PAYBACK      OF HEAT          HEAT        SURF.   INSUL.
  INSUL.    COST     PERIOD        SAVED           LOSS        TEMP.    COST
   (IN)  ($/SQ-FT)   (YRS)      ($/SQ-FT)   (BTU/HR-SQ-FT)    (F)   ($/SQ-FT)

   0.00     27.63     ****         0.00          667.31       248.0      0.00
   1.00      2.67     0.45        16.62           40.50       103.6      6.69
   2.00      1.95     0.47        17.13           21.38        94.1      7.22
   3.00      1.70     0.48        17.31           14.53        90.3      7.41
   4.00      1.64     0.53        17.40           11.02        88.2      7.98
   5.00      1.69     0.60        17.46            8.87        86.9      8.97

    **************************************************************************
    *
    *  ETI CORRESPONDS TO THE THICKNESS WITH THE LOWEST ANNUAL COST:     4.00IN
    *
    **************************************************************************



    HEAT SAVINGS AND PRESENT VALUES ARE PROJECTED ON GIVEN INPUT VARIABLES.
    ACTUAL VALUES MAY VARY DEPENDING ON THE ACTUAL SERVICE CONDITIONS.
```

```
                                                          SURFACE  5 OF  6

   PIPE OR SURFACE DESCRIPTION                 -   VERTICAL FLAT SURFACE RFN-1
   OPERATING TEMPERATURE                       -   221.0 F
   AMBIENT TEMPERATURE                         -    80.0 F
   PREVIOUS INSULATION                         -          NONE       (CODE  TYPE  0)
   NEW INSULATION                              -      FIBERGLASS     (CODE TYPE   3)
   PREVIOUS THICKNESS OF INSULATION            -   0.00 IN.
   HOURS OF OPERATION                          -  8760.0  PER YEAR
   REFERENCE THICKNESS OF INSULATION
                    FOR PAYBACK CALCULATION - 0.00 IN.
   PIPING COMPLEXITY FACTOR                    -  1.15
   CONDUCTIVITIES SUPPLIED BY USER    NEW - NONE SUPPLIED
                                      OLD - NONE SUPPLIED

  THICK.                            PRES. VALUE
  OF NEW   ANNUAL     PAYBACK       OF HEAT           HEAT           SURF.    INSUL.
  INSUL.    COST      PERIOD        SAVED             LOSS           TEMP.     COST
   (IN)   ($/SQ-FT)    (YRS)      ($/SQ-FT)    (BTU/HR-SQ-FT)      (F)   ($/SQ-FT)

   0.00     21.99      ****          0.00          531.05         221.0      0.00
   1.00      2.35      0.59         13.21           32.82          99.9      6.69
   2.00      1.79      0.62         13.62           17.36          91.9      7.22
   3.00      1.58      0.63         13.77           11.81          88.7      7.41
   4.00      1.55      0.69         13.84            8.96          86.9      7.98
   5.00      1.63      0.78         13.89            7.22          85.8      8.97

   ****************************************************************************
   *                                                                          *
   *  ETI CORRESPONDS TO THE THICKNESS WITH THE LOWEST ANNUAL COST:    4.00IN
   *                                                                          *
   ****************************************************************************


   HEAT SAVINGS AND PRESENT VALUES ARE PROJECTED ON GIVEN INPUT VARIABLES.
   ACTUAL VALUES MAY VARY DEPENDING ON THE ACTUAL SERVICE CONDITIONS.
```

```
                                                     SURFACE  6 OF  6

  PIPE OR SURFACE DESCRIPTION                  -   VERTICAL FLAT SURFACE E. Rm
  OPERATING TEMPERATURE                        -   176.0 F
  AMBIENT TEMPERATURE                          -    80.0 F
  PREVIOUS INSULATION                          -          NONE      (CODE  TYPE  0)
  NEW INSULATION                               -       FIBERGLASS   (CODE TYPE   3)
  PREVIOUS THICKNESS OF INSULATION             -   0.00 IN.
  HOURS OF OPERATION                           -  8760.0  PER YEAR
  REFERENCE THICKNESS OF INSULATION
                  FOR PAYBACK CALCULATION      - 0.00 IN.
  PIPING COMPLEXITY FACTOR                     -   1.15
  CONDUCTIVITIES SUPPLIED BY USER          NEW - NONE SUPPLIED
                                           OLD - NONE SUPPLIED

 THICK.
 OF NEW   ANNUAL    PAYBACK   PRES. VALUE
 INSUL.    COST     PERIOD    OF HEAT          HEAT          SURF.   INSUL.
  (IN)  ($/SQ-FT)   (YRS)     SAVED            LOSS          TEMP.    COST
                             ($/SQ-FT)   (BTU/HR-SQ-FT)      (F)   ($/SQ-FT)

  0.00    13.49      ****       0.00          325.73         176.0     0.00
  1.00     1.86      1.04       8.08           21.05          93.9     6.69
  2.00     1.53      1.09       8.34           11.17          88.3     7.22
  3.00     1.41      1.10       8.44            7.61          86.1     7.41
  4.00     1.42      1.19       8.48            5.78          84.8     7.98

  ***********************************************************************
  *
  *  ETI CORRESPONDS TO THE THICKNESS WITH THE LOWEST ANNUAL COST:   3.00IN
  *
  ***********************************************************************


  HEAT SAVINGS AND PRESENT VALUES ARE PROJECTED ON GIVEN INPUT VARIABLES.
  ACTUAL VALUES MAY VARY DEPENDING ON THE ACTUAL SERVICE CONDITIONS.
```

Thk.of new Insulation,in.	Annual Cost,$/ft.	Annual Saving,$/ft.	Insul.Cost $/ft.	Simple Payback Years
1	153.04	0	68.22	
2	88.60	64.44	77.61	1.20
3	67.43	85.61	93.78	1.10
4	56.83	96.21	103.90	1.08
5	51.02	102.02	114.30	1.12
6	47.75	105.29	125.72	1.19

From fiberglass, the manufacturer's analysis the economic thk. of insulation, ETI, is 6" thk. fiberglass for which the simple payback period is 1.19 years, say 1.20 yr.

With the new insulation, the heat loss at 26,664,000 Btu/day will be reduced to about

$$26{,}664{,}000 \times (704/42362 + 23/2633)\tfrac{1}{2} = 324{,}000 \text{ Btu/day}$$

for a saving of

$$26{,}664{,}000 - 324{,}000 = 26{,}340{,}000 \text{ Btu/day}$$

which can be utilized in the predryer.

Using calculated savings, the simple payback period is

$$125.72 \times 300/26.34 \times \$4.20 \times 365 = 0.93 \text{ year.}$$

Agreement 0.93 vs 1.20 is reasonably close.

Kiln - Material and Energy Balance for Acid Brick

Use same terminology as for dryer.

All energy values referred to a temperature base of 80^{o}F (except 75^{o}F for calculation of surface heat loss).

Gross heating value of natural gas is 1038 Btu/ft.^{3}

Net heating value of natural gas is 936 Btu/ft.^{3}

A. Energy Balance

1. Heat input

a. Natural gas

$$q1 = 370{,}000 \times 1038 = 384{,}060{,}000 \text{ Btu/day}$$

b. Cooling air

Air enters cooling section at $93^{\circ}F$

$$q2 = 5{,}950 \times 1.085 \times (93 - 80) \times 24$$

$$= 2{,}014{,}000 \text{ Btu/day}$$

c. Ware

Ware enters kiln at $355^{\circ}F$

$$q3 = 10{,}472 \times 12 \times 0.22\ (355 - 80)$$

$$= 7{,}603{,}000 \text{ Btu/day}$$

d. Car Refractory

$$q4 = 2300 \times 12 \times 0.22\ (355 - 80)$$

$$= 1{,}670{,}000 \text{ Btu/day}$$

e. Car Steel

$$q5 = 1800 \times 12 \times 0.11\ (355 - 80)$$

$$= 653{,}000 \text{ Btu/day}$$

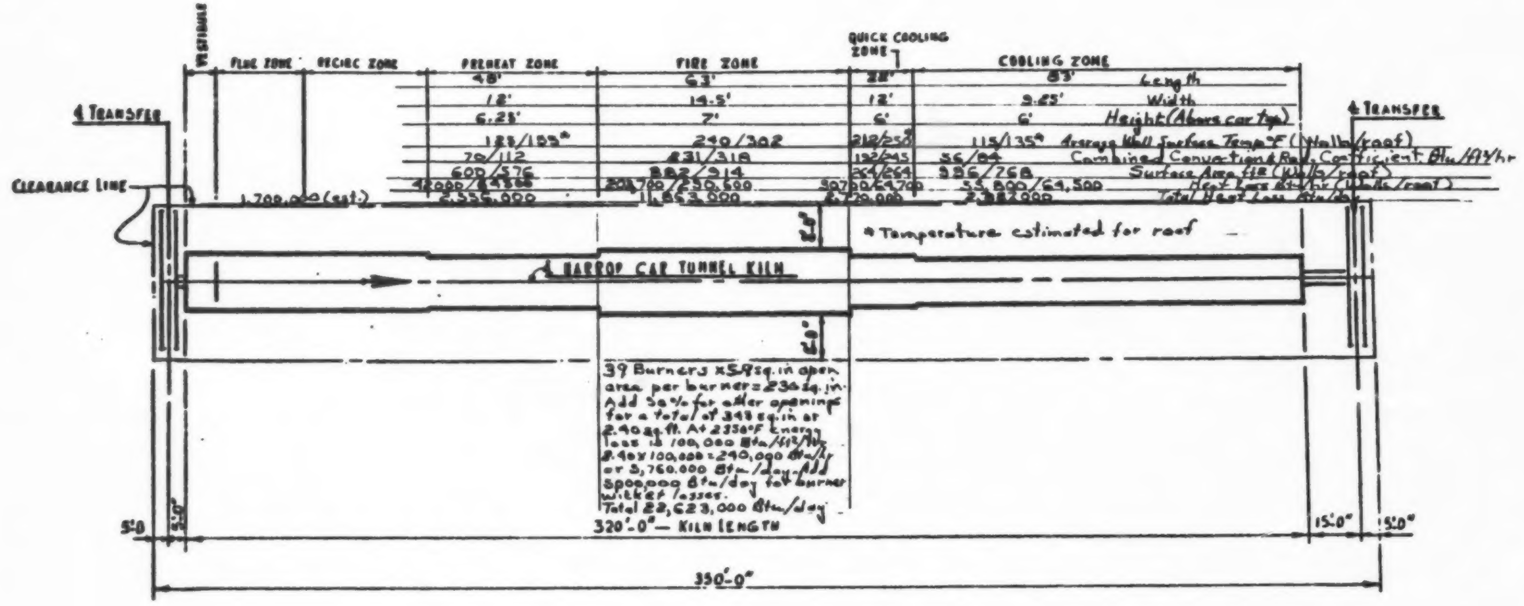
f. Total Heat Input

$$Qi = 384{,}060{,}000 + 7{,}604{,}000 + 1{,}670{,}000 + 653{,}000 + 2{,}014{,}000 = 396{,}001{,}000 \text{ Btu/day}$$

g. Gross Input of Natural Gas Heat Per Pound of Ware

$$= 384{,}060{,}000/10{,}472 \times 12 \times 0.954$$

$$= 3204 \text{ Btu/lb.}$$



Flue zone / Recirc zone	Preheat zone	Fire zone	Quick cooling zone	Cooling zone	
	48'	63'	28'	83'	Length
	12'	14.5'	12'	9.25'	Width
	6.25'	7'	6'	6'	Height (Above car top)
	183/155*	240/302	212/250*	115/135*	Average Wall Surface Temp °F (Walls/roof)
	70/112	231/318	192/245	56/84	Combined Convection & Rad. Coefficient Btu/ft²/hr
	600/576	882/914	264/264	936/768	Surface Area ft² (Walls/roof)
	42000/64512	203,700/290,600	50700/64700	55,800/64,500	Heat Loss Btu/hr (Walls/roof)
1,700,000 (est.)	2,555,000	11,853,000	2,720,000	2,382,000	Total Heat Loss Btu/day

* Temperature estimated for roof

39 Burners x 5.9 sq. in open area per burner = 230 sq. in. Add 50% for other openings for a total of 345 sq. in or 2.40 sq. ft. At 2350°F Energy loss is 100,000 Btu/ft²/hr. 2.40 x 100,000 = 240,000 Btu/hr or 5,760,000 Btu/day. Add 5000,000 Btu/day for burner wicket losses.
Total 22,623,000 Btu/day

PLAN

Total Surface Heat Loss (75° ambient air) = 32,536,000 Btu/day

PLANT LAYOUT
FOR
CLAYBURN-HARBINSON, LTD
ABBOTSFORD, B.C., CANADA

HARROP CERAMIC SERVICE CO.
ENGINEERS & CONSTRUCTORS
35 E. GAY STREET
COLUMBUS, OHIO

SCALE LENGTH - 1"=[illegible]
WIDTH - 1"=[illegible]
DATE 6-1-196[illegible]
DRAWN BY JFH
CHECKED BY
APPROVED
4691-1-1
REV NO

2. Heat Output

Ware leaves kiln at 150°F

a. Hot air to dryer.

From calculations for dryer

$q1 = 106,642,000$ Btu/day

b. Ware

$q2 = 10,472 \times 12 \times 0.22\ (150 - 80)$

$= 1,935,000$ Btu/day

c. Car Refractory

$q3 = 2300 \times 12 \times 0.22\ (150 - 80)$

$= 425,000$ Btu/day

d. Car Steel

$q4 = 1800 \times 12 \times 0.11\ (150 - 80)$

$= 166,000$ Btu/day

e. Surface Heat Loss

Estimated on separate sheet is 32,536,000 Btu/day

f. Stack Heat Loss

Volume of exhaust air measured is 26,890 scfm which is

$26,890 \times 0.0808 \times 1440 = 3,129,000$ lb./day

Humidity of ambient air is 0.0079

Water formed by burning natural gas,

$370,000 \times 2.025/1248 = 600.4$ lb./day

Humidity of exhaust air then is

$0.0079 + 600.4/3,129,000 = 0.0081$

Enthalpy of ambient air is

$H_1 = 0.24 \times 80 + 0.0079 \times 1097$

$= 27.9$ Btu/lb.

Enthalpy of exhaust air at 340°F,

$H_3 = 0.24 \times 340 + 0.0081 \times 1221.1$

$= 81.6 + 9.89 = 91.49$ Btu/lb.

Stack heat loss

$L_c = 3{,}129{,}000\ (91.49 - 27.9)$

$= 198{,}973{,}000$ Btu/day

6. Total Heat Output

106,642,000
1,935,000
425,000
166,000
32,536,000
198,973,000

= 340,677,000 Btu/day

Heat Input = Heat Output + Unaccounted heat losses

Unaccounted heat losses = 393,987,000 - 340,677,000

= 53,310,000 Btu/day

Note: See summary table on following page.

B. Air Balance

There are two separate systems:

1. Preheat and firing zones
2. Cooling zone

1. Preheat and Firing Zones

Gases leaving = gases exhausted + gases backdrafted.

Gase exhausted: 26,890 scfm.

Gases backdrafted:
O_2 conc. in hot air takeoff: 19.5%
O_2 conc. of flue gas at end of firing zone: 2.6%
O_2 conc. in cooling air: 20.8%
Vol. of hot air leaving: 5700 scfm
Let V = vol. of flue gas in scfm
Then
$(V \times 2.6) + (5700 - V)\ 20.8 = 5700 \times 19.5$
Solving
$V = 407$ scfm

Item	Input	Output	
	X 1000 Btu/day	X 1000 Btu/day	Percent
Provision by fuel	384,060		
Provision by ware charges	9,927		
Provision by cooling air	2,014	0	
Flue gas losses	-	198,973(1)	50.2
Heat recovery losses - hot air to dryer	-	106,642	26.9
Losses due to discharge of ware and cars	-	2,526	0.6
Radiation & convection losses	-	32,536	8.3
Irreversible reaction losses	-	35,640	9.0
(Assumed 9% of input)			5.0
Unaccounted losses		19,684	
Totals	396,001	396,001	100.0

(1) Of which 175,749,000 is for heating infiltered air (see air balance).

Gases leaving = 26,890 + 407 = 27,297 scfm (at 32°F)

Gases entering = Air supplied by excess air burners + products of combustion + infiltered air.

a. Air supplied by H.V. burners (North American 4442-3)
19 burners with 24 osi air, 2.5" W.C. gas
19 x 2000 cfh/burner = 38,000 cfh (at 70°F)

14 burners with 15" W.C. ΔP on air, 2.25" W.C. P on gas
14 x 1700 cfh/burner = 23,800 cfh (at 70°F)

b. Combustion products
Gas consumption = 370,000 cfd

Vol. of combustion products
= 370,000/24 x 11
= 169,600 cfh (at 70°F)

Total volume of air and combustion products at 32°F
= (38,000 + 23,800 + 169,600) x 492/535
= 212,800 scfh
= 3,547 scfm

Air leaving = Air entering
27,297 = 3,547 + Infiltered air vol.

Infiltered air vol. = 23,750 scfm.

Air infilters mainly in preheat zone which is under negative pressure.

The infiltered air must be heated to exhaust temperature of 340°F requiring a heat input of:

23,750 x 1440 x 0.0808 x (91.49 - 27.9) = 175,749,000 Btu/day

which is 88.3% of the total flue gas loss of 198,973,000 Btu/day.

2. Cooling Zone

Air balance is difficult because hot air to dryer is diluted with ambient air at relief ports and some of the air supplied by the cooling air fan leaves the kiln exit - both of which could not be measured.

C. Exhaust Heat Recovery From Kiln Acid Brick

Flow is 26,890 scfm at 340°F

To avoid corrosion exhaust stream is to leave air to air heat exchanger at 240°F.

$H340 = 0.24 \times 340 + 0.0081 \times 1221.1$

$= 91.49$ Btu/lb.

$H240 = 0.24 \times 240 + 0.0081 \times 1164.2$

$= 57.80 + 9.43$

$= 67.23$ Btu/lb.

Heat recoverable $= 26{,}890 \times 0.0808 \times 1440 \times (91.49 - 67.23)$

$= 75{,}902{,}000$ Btu/day

See Z-Air Inc. analysis on following sheets for heat recovery.

D. Insulation of Firing Zone Roof

Max. zone temp.: 2350°F
Surface temperature: 302°F
Roof area: 1,400 sq. ft.
Roof construction: 9" silica brick
4½" 2300°F insulating brick
2" effective diatomaceous earth remaining.

k values for the above materials are 14.3, 1.20 and 0.60 Btu per hr., sq. ft., °F per inch in the order listed.

$$\frac{1}{U} = \frac{9}{14.3} + \frac{4.5}{1.20} + \frac{2}{0.60} = 0.629 + 3.75 + 3.33$$

$$= 0.130$$

$$L_s = 24 \times 0.130 \times 1400 \times (2350 - 302)$$
$$= 8{,}946{,}000 \text{ Btu/day.}$$

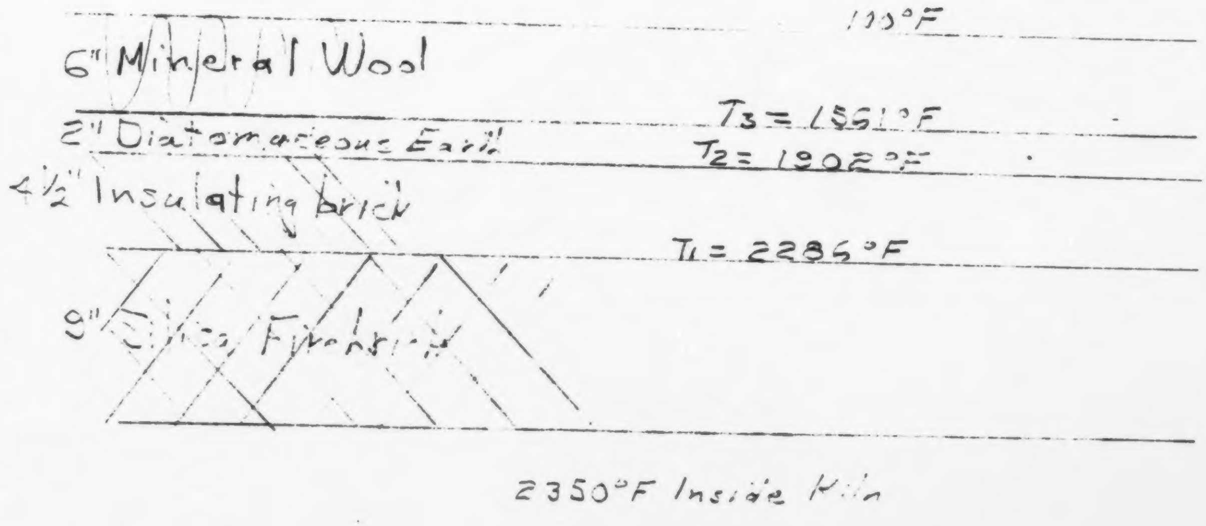
Insulate with 6"thk. mineral wool ~~fiberglass semi-rigid board or blanket~~ insulation, k = 0.42 (at 400°F)

$$\frac{1}{U^1} = \frac{9}{14.3} + \frac{4.5}{1.20} + \frac{2}{0.60} + \frac{6}{0.42}$$
$$= 0.629 + 3.75 + 3.33 + 14.28$$
$$U^1 = 0.0455$$

Assume a surface temperature of 100°F, then

$$L_s^1 = 24 \times 0.0455 \times 1400 \times (2350 - 100)$$
$$= 3{,}440{,}000 \text{ Btu/hr.}$$

Check max. temp. of new insulation.



2350°F Inside Kiln

$$\frac{14.3}{9} (2350 - T_1)\ 1400 \times 24 = 3,440,000$$

$$2350 - T_1 = 64$$

$$T_1 = 2286^\circ F$$

$$\frac{1.20}{4.5} (2286 - T_2)\ 1400 \times 24 = 3,440,000$$

$$2286 - T_2 = 384$$

$$T_2 = 1902$$

$$\frac{0.60}{2} (1902 - T_3)\ 1400 \times 24 = 3,440,000$$

$$1902 - T_3 = 341$$

$$T_3 = 1561^\circ F$$

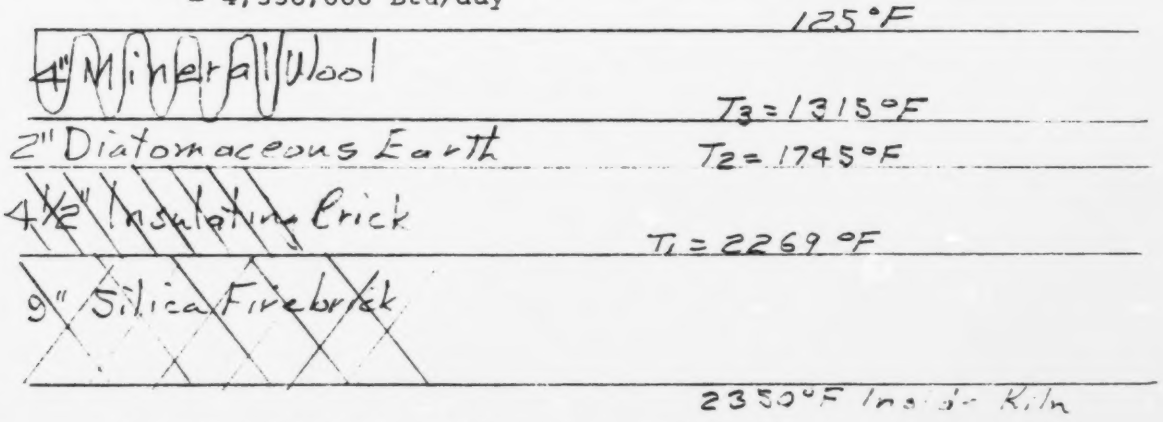
2286°F OK for 2300°F insulating brick
1561°F too high for mineral wool (limitation about 1300°F)

Use 4" thk. mineral wool.

Then $U^1 = 0.0580$

Assume a surface temperature of 125°F, then

$$L_s{}^1 = 24 \times 0.0580 \times (2350 - 125) \times 1400$$
$$= 4,336,000 \text{ Btu/day}$$



$$14.3/9\ (2350 - T_1)\ 1400 \times 24 = 4,336,000$$

$$2350 - T_1 = 81$$

$$T_1 - 2269^\circ F$$

$$1.20/4.5\ (2269 - T_2)\ 1400 \times 24 = 4,336,000$$

$$2229 - T_2 = 484$$

$$T_2 = 1745^\circ F$$

$$0.60/2\ (1745 - T_3)\ 1400 \times 24 = 4,336,000$$

$$1745 - T_3 = 430$$

$$T_3 = 1315^\circ F$$

Use 4" thk. mineral wool. Cost \$0.78/ft.^{2} for 2" thk.
Cost applied, \$2.50/ft.^{2}
Total cost: 1400 x 2.50 = \$3500.

Energy saving: 8,946,000 - 4,336,000 = 4,610,000 Btu/day.

$$\text{Simple payback period} = \frac{\$3500}{\$4.20 \times 4.61 \times 365}$$

$$= 0.50 \text{ yr.}$$

Des Champs Laboratories Incorporated
Box 440, East Hanover, NJ 07936

Z-DUCT Z-PACK MINI-Z-PACK THERMO-Z EZ-AIRE EZ-VENT

.... THERMODYNAMIC ANALYSIS ....

Representative: KENT ENGINEERING LTD
Job Name:

Prepared by: Z-AIR INC.
Date: 09/25/85

JOB NOTES:
1) EXHAUST @ 400 F LIMITED TEMP. AFTER EXCHANGER 230 F
2) MAXIMUM SCFM INTAKE TO KEEP THESE CONDITIONS WITH 30000 SCFM EXHAUST

SERIES 75 COUNTER FLOW RUN DESCRIPTION: MODELS 75

****

SCFM RATING OF Z-DUCT IS= 20000 WIDTH OF FOIL IS= 36 INCHES DEPTH OF FOLD IS= 16 INCHES
PLATE SPACING: SIDE 1-2 .1825 INCHES ALTITUDE: 0 FEET SURFACE AREA: 13760 FT SQUARED
************* SIDE 3-4 .3075 INCHES PLATE MATERIAL:316 PLATE THICKNESS: .005 INCHES

	SCFM12	SCFM34	T1	T2	T3	T4	T1DP	T3DP	HR1	HR2	HR3	HR4	h1	h2	h3	h4	COND	P12	P34	eff	Q
RUN # 1	14000	30000	0	316	400	256	4	51	.001	.001	.008	.008	1.1	76.7	106.0	70.3	0	1.12	1.29	.789	4750208
RUN # 2	15000	30000	0	309	400	249	4	51	.001	.001	.008	.008	1.1	74.9	106.0	68.7	0	1.26	1.28	.772	4972394
RUN # 3	16000	30000	0	302	400	243	4	51	.001	.001	.008	.008	1.1	73.2	106.0	67.1	0	1.40	1.27	.754	5181958
RUN # 4	17000	30000	0	295	400	237	4	51	.001	.001	.008	.008	1.1	71.6	106.0	65.6	0	1.55	1.27	.737	5379707
RUN # 5	18000	30000	0	288	400	231	4	51	.001	.001	.008	.008	1.1	70.0	106.0	64.2	0	1.71	1.26	.721	5566418
RUN # 6	19000	30000	0	282	400	226	4	51	.001	.001	.008	.008	1.1	68.4	106.0	62.9	0	1.87	1.25	.705	5742827
RUN # 7	20000	30000	0	276	400	220	4	51	.001	.001	.008	.008	1.1	66.9	106.0	61.6	0	2.04	1.25	.689	5909629
RUN # 8	21000	30000	0	270	400	216	4	51	.001	.001	.008	.008	1.1	65.4	106.0	60.5	0	2.21	1.24	.674	6067472

GLOSSARY OF TERMS:
[T1,T2,T3,T3DP,T4] are Temperatures in Fahrenheit degrees
[HR] is humidity ratio in lbs H2O per lb of dry air
[eff] is effectiveness Q/Qmaximum
[h1,h2,h3,h4] are enthalpies in BTU's/lb
[Q] is BTU's/hr recovered at the given conditions
[DP] is Suffix for dewpoint condition
[COND] is condensate in lbs/hr
[P12 & P34] are pressure drop in inches water column
[h12 & h34] are heat transfer coefficients in BTU's/ft2/hr/F
[SCFM12,SCFM34] are volume flow rates at standard conditions

NOTES:
1)

Des Champs Laboratories Incorporated
Box 440, East Hanover, NJ 07936

Z-DUCT Z-PACK MINI-Z-PACK THERMO-Z EZ-AIRE EZ-VENT

.... THERMODYNAMIC ANALYSIS............................

Representative: KENT ENGINEERING LTD
Job Name:

Prepared by: Z-AIR INC.
Date: 09/25/85

JOB NOTES:
1) EXHAUST @ 300 F LIMITED TEMP. AFTER EXCHANGER 230 F
2) MAXIMUM SCFM INTAKE TO KEEP THESE CONDITIONS WITH 30000 SCFM EXHAUST

```
SERIES 75 COUNTER FLOW          RUN DESCRIPTION:  MODELS 75
**************************************************************************************************************
SCFM RATING OF Z-DUCT IS= 20000     WIDTH OF FOIL IS= 36 INCHES     DEPTH OF FOLD IS= 16 INCHES
          PLATE SPACING: SIDE 1-2 .1825 INCHES     ALTITUDE: 0 FEET   SURFACE AREA: 13760  FT SQUARED
          *************  SIDE 3-4 .3075 INCHES     PLATE MATERIAL:316  PLATE THICKNESS: .005  INCHES
  SCFM12  SCFM34   T1   T2   T3   T4 T1DP T3DP  HR1   HR2   HR3   HR4    h1    h2    h3    h4 COND  P12  P34  eff        Q
RUN # 1
    6000   30000    0  280  300  245    4   51 .001  .001  .008  .008   1.1  67.9  81.2  67.7    0  .24 1.20 .933  1800842
RUN # 2
    7000   30000    0  275  300  237    4   51 .001  .001  .008  .008   1.1  66.7  81.2  65.7    0  .31 1.19 .916  2060555
RUN # 3
    8000   30000    0  269  300  230    4   51 .001  .001  .008  .008   1.1  65.3  81.2  63.9    0  .39 1.18 .897  2306894
RUN # 4
    9000   30000    0  264  300  222    4   51 .001  .001  .008  .008   1.1  63.9  81.2  62.1    0  .48 1.17 .878  2540007
RUN # 5
   10000   30000    0  258  300  216    4   51 .001  .001  .008  .008   1.1  62.6  81.2  60.5    0  .58 1.16 .859  2760235
RUN # 6
   11000   30000    0  252  300  209    4   51 .001  .001  .008  .008   1.1  61.2  81.2  58.9    0  .68 1.16 .840  2968057
RUN # 7
   12000   30000    0  246  300  203    4   51 .001  .001  .008  .009   1.1  59.8  81.2  57.4    0  .79 1.15 .822  3164036
RUN # 8
   13000   30000    0  241  300  197    4   51 .001  .001  .008  .008   1.1  58.5  81.2  56.0    0  .91 1.15 .803  3348784
```

GLOSSARY OF TERMS:
[T1,T2,T3,T3DP,T4] are Temperatures in Fahrenheit degrees
[HR] is humidity ratio in lbs H2O per lb of dry air
[eff] is effectiveness Q/Qmaximum
[h1,h2,h3,h4] are enthalpies in BTU's/lb
[Q] is BTU's/hr recovered at the given conditions
[DP] is Suffix for dewpoint condition
[COND] is condensate in lbs/hr
[P12 & P34] are pressure drop in inches water column
[h12 & h34] are heat transfer coefficients in BTU's/ft2/hr/F
[SCFM12,SCFM34] are volume flow rates at standard conditions

Kiln Gas Consumption Division

For acid brick - 370,000 ft.^{3}/day = 15,417 ft.^{3}/hr.

Gas consumption in preheat by H.V. burners:

16 burners on gas ΔP of 2.5"w.c. - 16 x 201 = 3216
11 burners on gas ΔP of 2.0"w.c. - 11 x 180 = 1980
3 burners on gas ΔP of 1.5"w.c. - 3 x 156 = 468

$$= 5,664 \ \frac{\text{ft.}^3}{\text{hr.}}$$

Gas consumption in firing zone:

15,417 - 5,664 = 9,753 ft.^{3}/hr.

Total combustion air requirement of firing zone is:
9,753 x 10/60 x 492/535 = 1495 scfm

For 20% excess air, the air requirement would be:
1,495 x 1.20 = 1,794 scfm

Total combustion air requirement of preheat zone is:
5,664 x 10/60 x 492/535 = 868 scfm

or 1,041 scfm at 20% excess air.

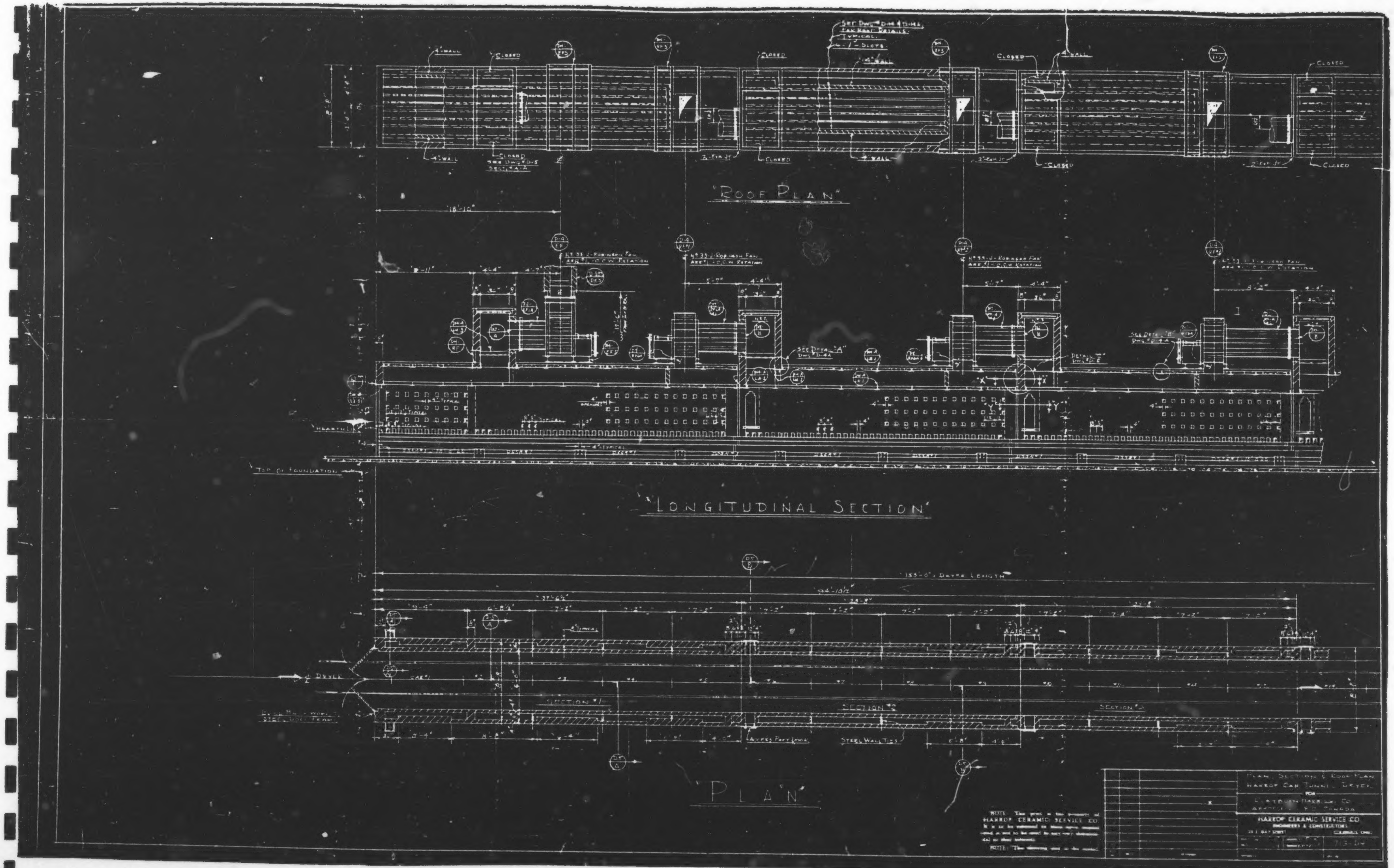
Total combustion air requirement = 2,363 scfm (32°F)

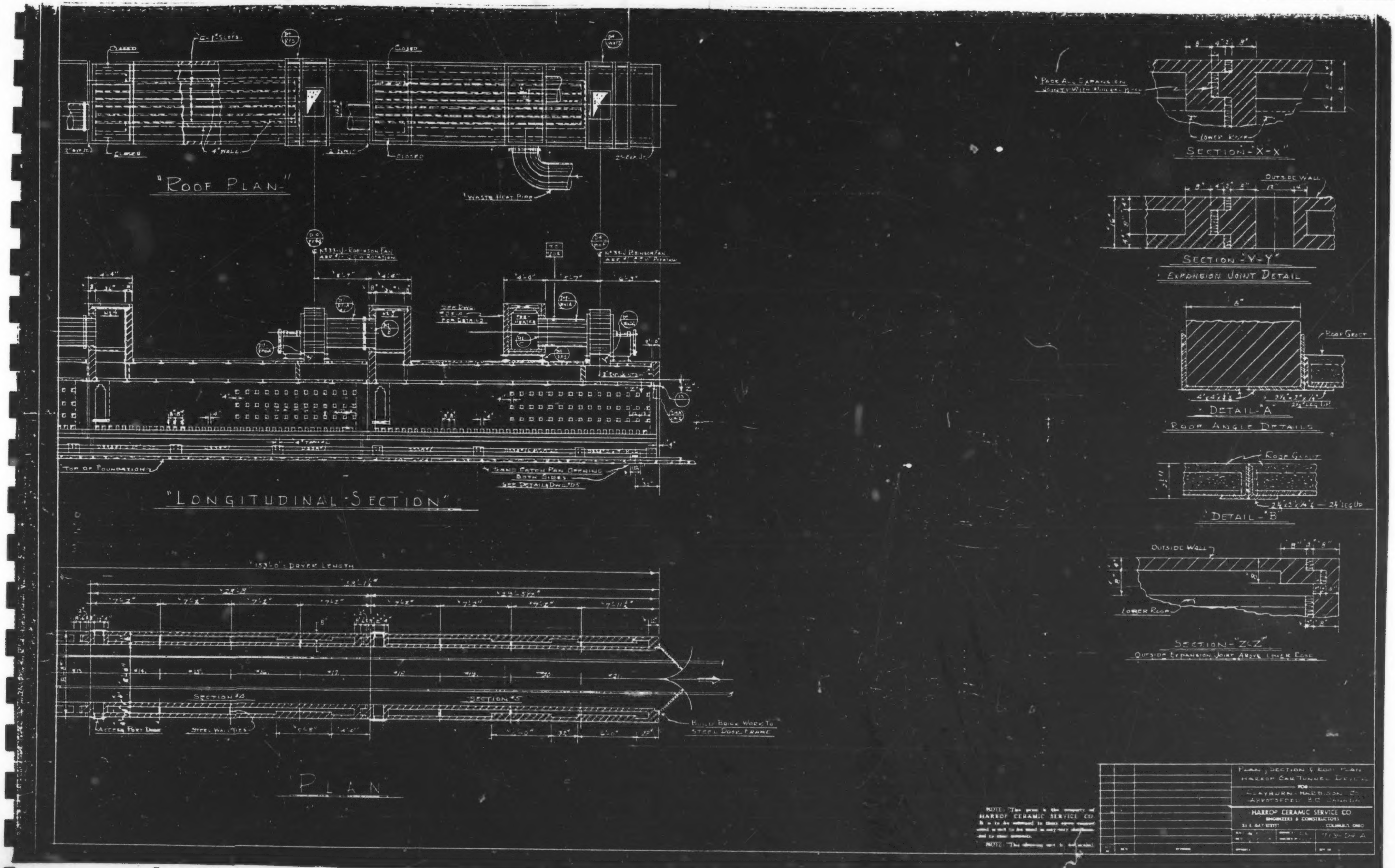
or 2,835 scfm at 20% excess air.

Blower capacity: 3,500 cfm (at 70°F)

or 3,249 scfm (at 32°F)

APPENDIX F - HARROP DRAWINGS FOR KILN AND DRYER

"ROOF PLAN"
"LONGITUDINAL SECTION"
"PLAN"
4" WALL
CLOSED
CLOSED SEE DWG D-5 SECT. A-A
SEE DWG D-4 & D-4A FOR ROOF DETAILS TYPICAL
18'-10"
No 33 J. ROBINSON FAN ARR. #1 C.C.W. ROTATION
SEE DETAIL "A" DWG D-4
SEE DETAIL "B" DWG D-4A
HEARTH
TOP OF FOUNDATION
133'-0" DRYER LENGTH
94'-10½"
37'-6¾"
℄ DRYER
SECTION #1
SECTION #2
SECTION #3
ACCESS PORT DOOR
STEEL WALL TIES
7'-2"
6'-8"
4'-6"
NOTE: This print is the property of HARROP CERAMIC SERVICE CO.
PLAN, SECTION & ROOF PLAN
HARROP CAR TUNNEL DRYER
FOR
CLAYBURN-HARBISON CO.
ABBOTSFORD, B.C. CANADA
HARROP CERAMIC SERVICE CO.
ENGINEERS & CONSTRUCTORS
35 E. GAY STREET
COLUMBUS, OHIO
713-D4



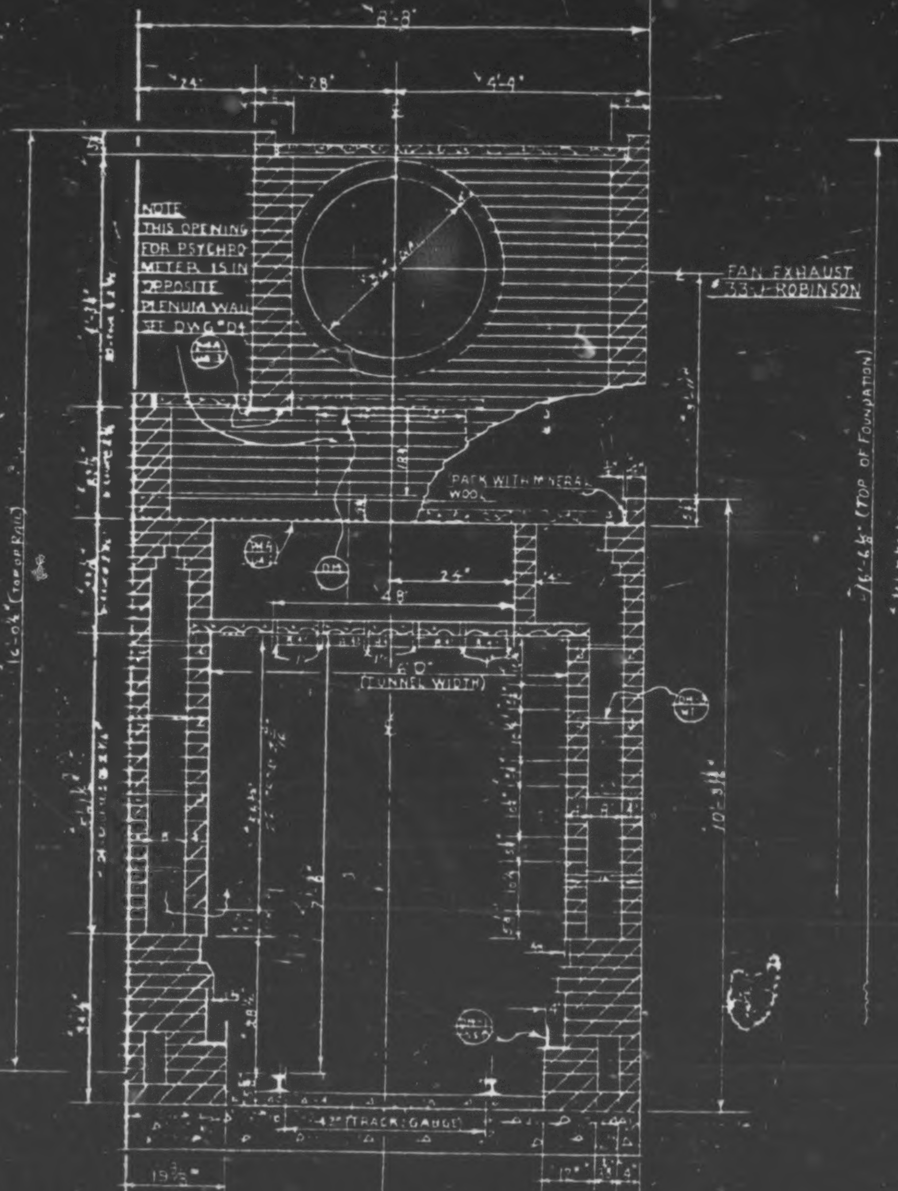
NOTE: This print is the property of HARROP CERAMIC SERVICE CO. [illegible]

NOTE: This drawing [illegible]

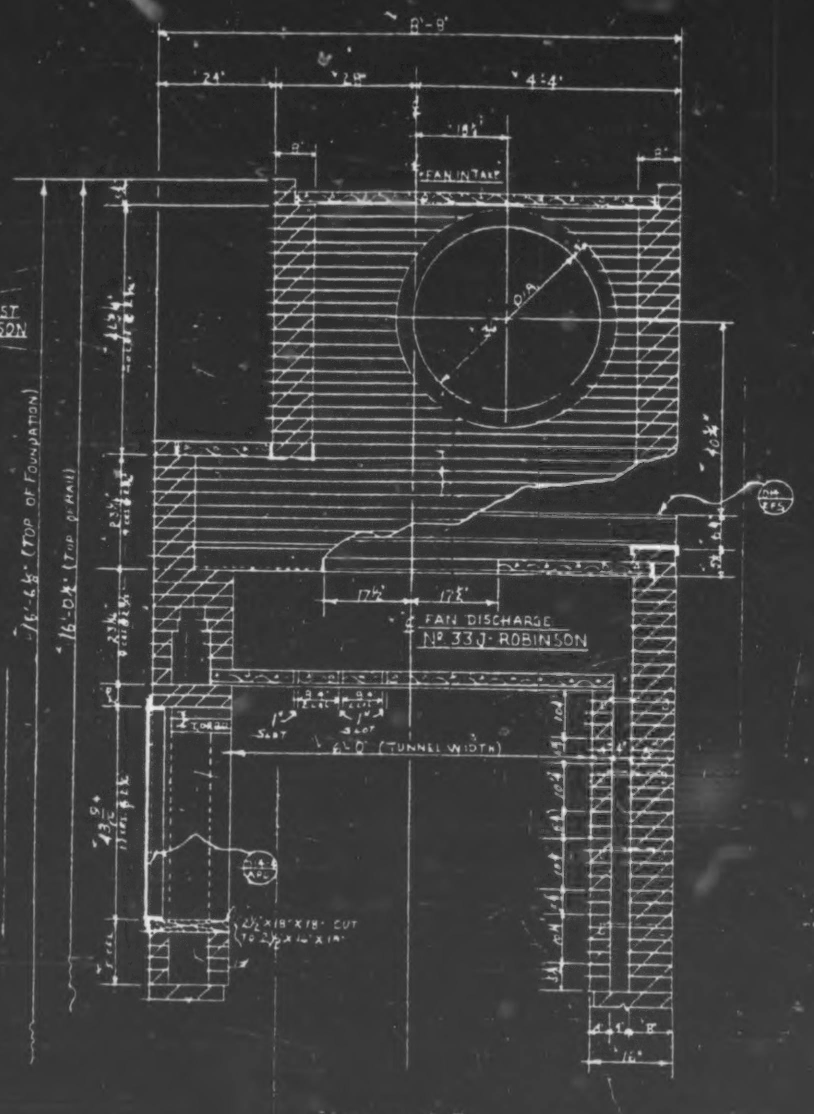
PLAN, SECTION & ROOF PLAN
HARROP CAR TUNNEL DRYER
FOR
CLAYBURN-HARRISON CO.
ABBOTSFORD, B.C. CANADA

HARROP CERAMIC SERVICE CO
ENGINEERS & CONSTRUCTORS
35 E. GAY STREET COLUMBUS, OHIO

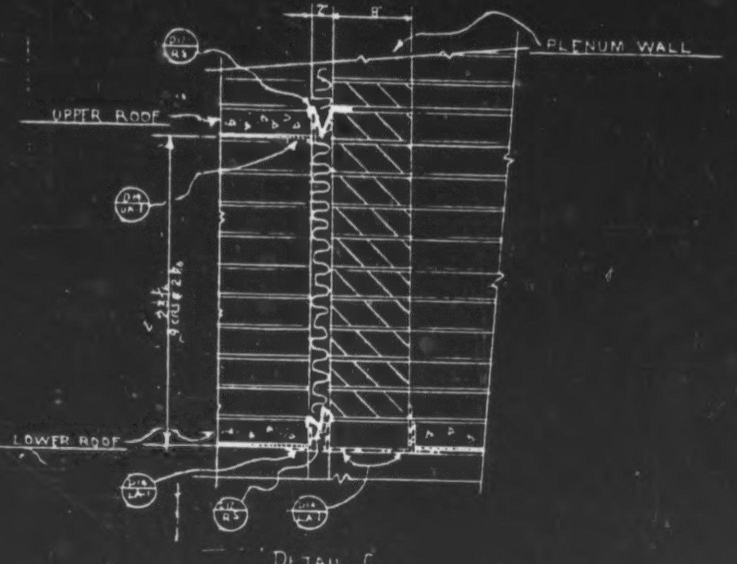
7734-D4-A



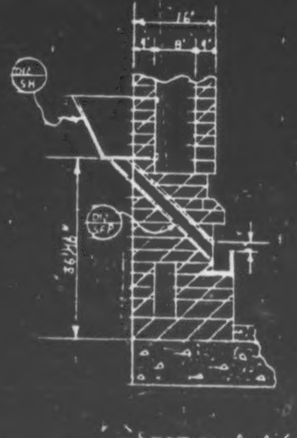
SECTION A-A



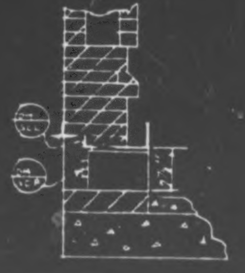
SECTION B-B



DETAIL C
SEE DWG D-4



SECTION A-A1



SAND CATCH PAN DETAIL

NOTE: This print is the property of HARROP CERAMIC SERVICE CO. It is to be returned to them upon request and is not to be used in any way detrimental to their interests.

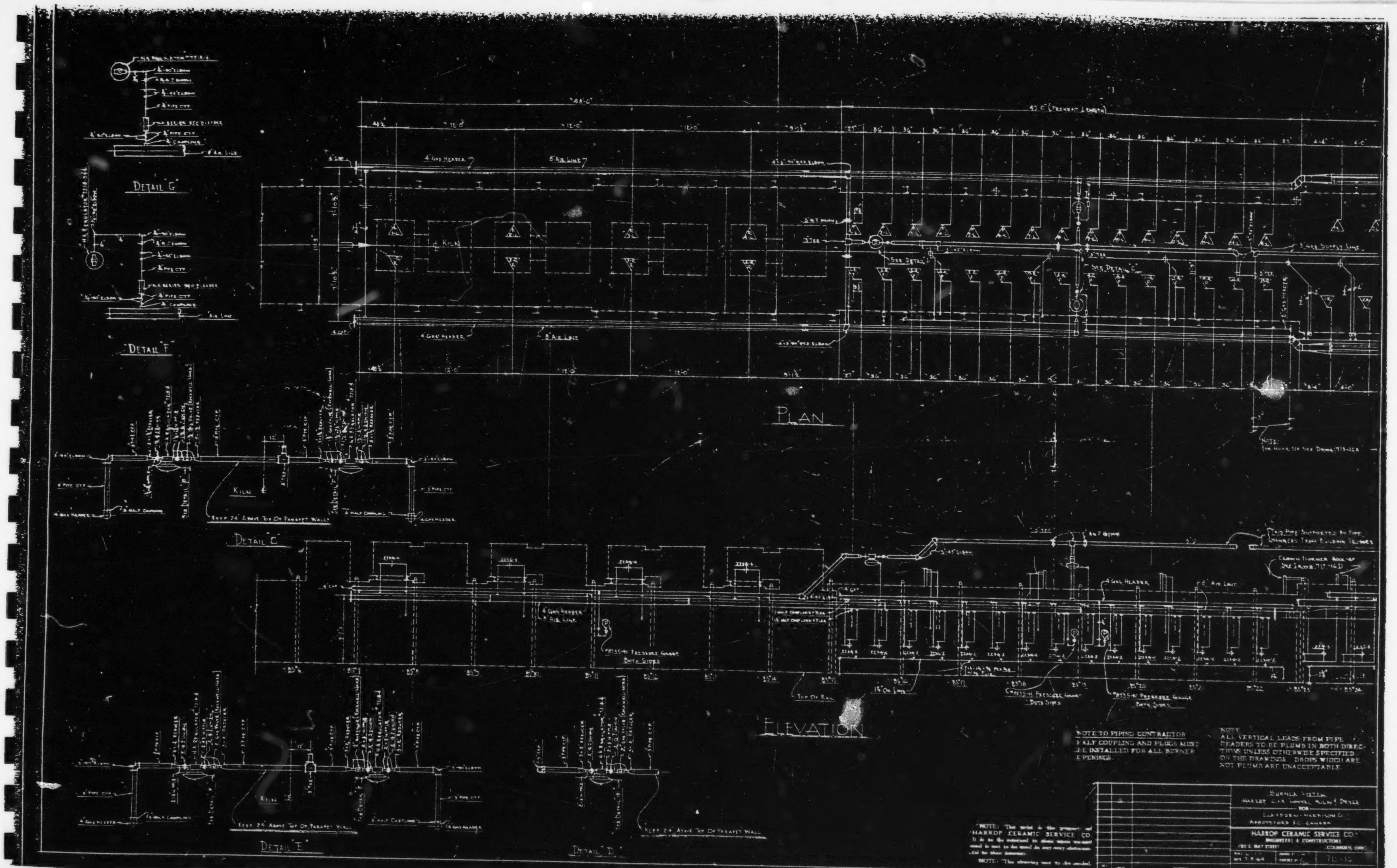
NOTE: This drawing must not be scaled.

A	7/1/64	Section "A-A" - Rev.
		Dim. - 19⅞" - 12'-3½" - 9"

DRYER SECTIONS
HARROP CAR TUNNEL KILN & DRYER
FOR
CLAYBURN-HARBISON LTD
ABBOTSFORD B.C. CANADA

HARROP CERAMIC SERVICE CO
ENGINEERS & CONSTRUCTORS
35 E. GAY STREET
COLUMBUS, OHIO

713-D5


Detail "G"
Detail "F"
PLAN
Detail "C"
ELEVATION
Detail "E"
Detail "D"
4" Gas Header
6" Air Line
Kiln
Keep 24" Above Top Of Parapet Wall
5" Gas Supply Line
See Detail "C"
Top Of Rail
4" Gas Header
6" Air Line
8735-N Pressure Gauge Both Sides
Crown Burner Hook-up See Drwg. 715-14D
This Pipe Supported By Pipe Hangers From Building Trusses

NOTE TO PIPING CONTRACTOR
HALF COUPLING AND PLUGS MUST BE INSTALLED FOR ALL BURNER OPENINGS.

NOTE:
ALL VERTICAL LEADS FROM PIPE HEADERS TO BE PLUMB IN BOTH DIRECTIONS UNLESS OTHERWISE SPECIFIED ON THE DRAWINGS. DROPS WHICH ARE NOT PLUMB ARE UNACCEPTABLE.

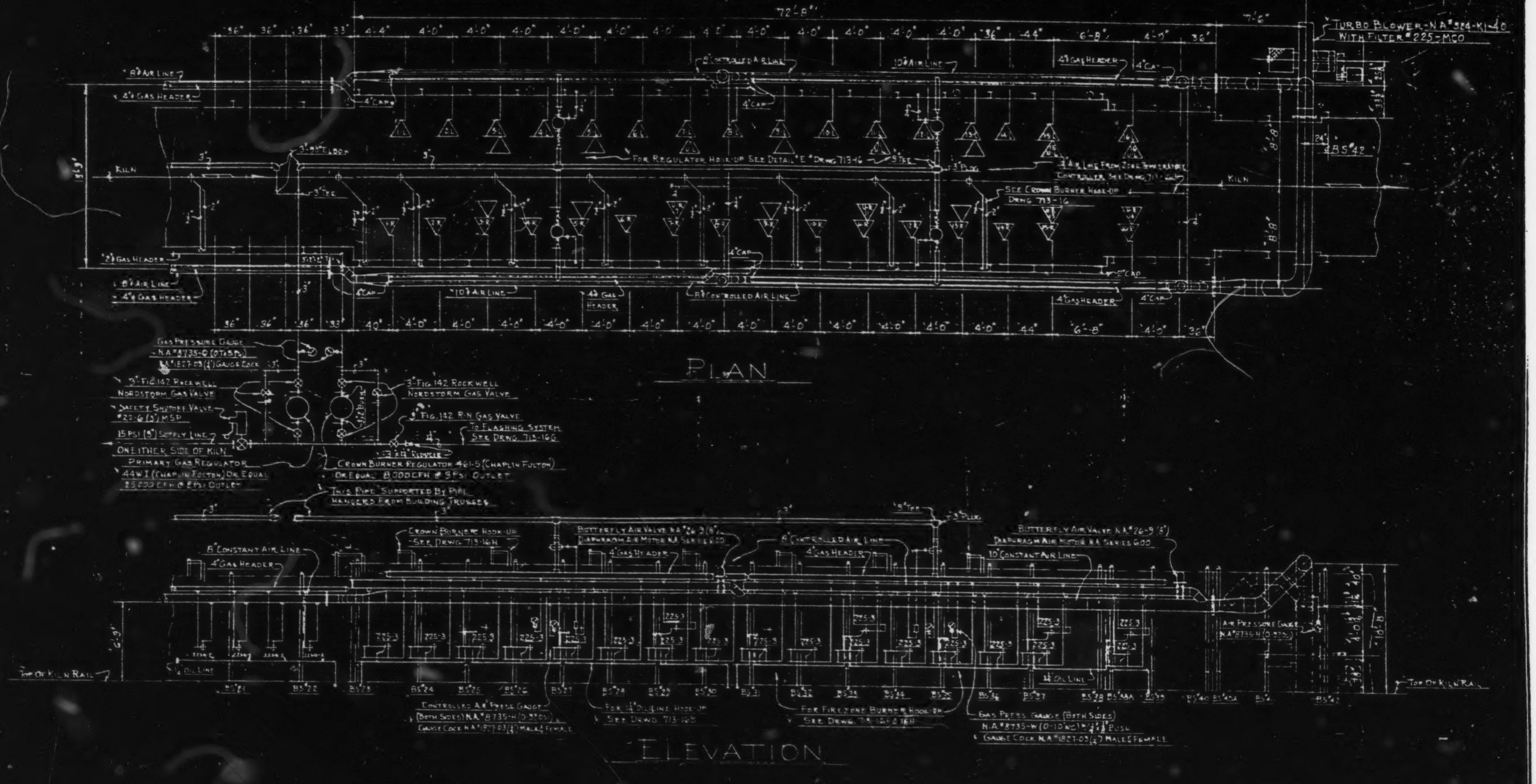
NOTE: This print is the property of HARROP CERAMIC SERVICE CO. It is to be returned to them upon demand and is not to be used in any way detrimental to their interests.

NOTE: This drawing not to be scaled.

Burner System
Harrop Car Tunnel Kiln & Dryer
FOR
Clayburn-Harrison Co.
Abbotsford B.C. Canada

HARROP CERAMIC SERVICE CO.
ENGINEERS & CONSTRUCTORS
35 E. GAY STREET COLUMBUS, OHIO

715-15



NOTE
ALL VERTICAL DRAINS FROM PIPE HEADERS TO BE PLUMB IN BOTH DIRECTIONS UNLESS OTHERWISE SPECIFIED ON THE DRAWINGS. DROPS WHICH ARE NOT PLUMB ARE UNACCEPTABLE.

NOTE TO PIPING CONTRACTOR
HALF COUPLINGS AND PLUGS MUST BE INSTALLED FOR ALL BURNER OPENINGS.

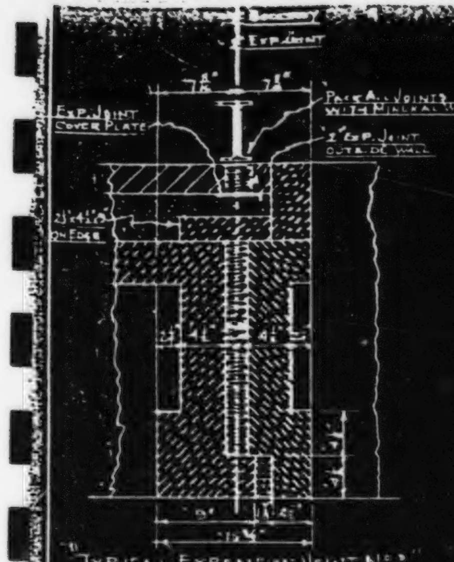
NOTE: This print is the property of HARROP CERAMIC SERVICE CO. It is to be returned to them upon request and is not to be used in any way detrimental to their interests.

NOTE: This drawing must not be scaled.

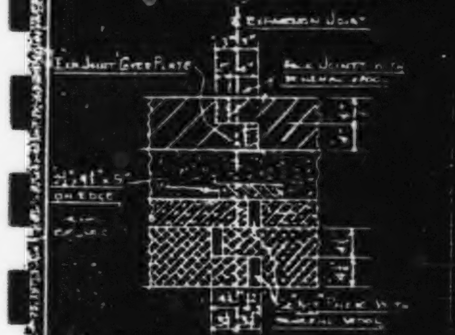
BURNER SYSTEM
HARROP CAR TUNNEL KILN & DRYER
FOR
CLAYBURN-HARBINSON CO.
ABBOTSFORD, B.C. CANADA

HARROP CERAMIC SERVICE CO.
ENGINEERS & CONSTRUCTORS
35 E. GAY STREET
COLUMBUS, OHIO

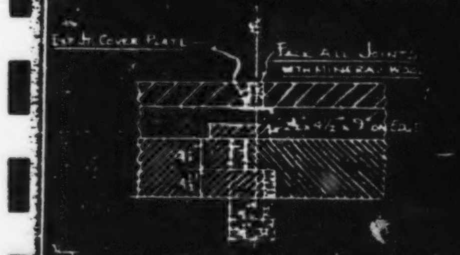
DATE 7-8-60
713-16A



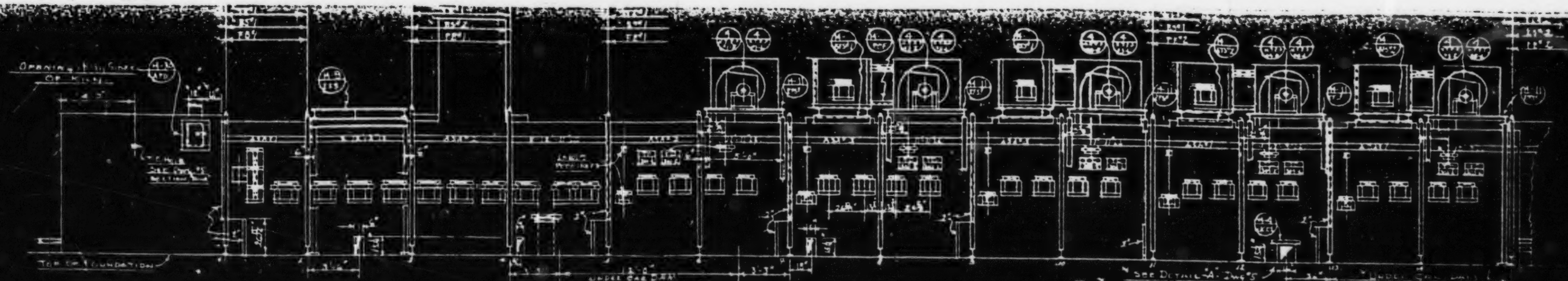
"TYPICAL EXPANSION JOINT No 3"
USED ONLY – IN CHARGING RECIRCULATING ZONE – DWG
FROM HEARTH TO SPRING LINE ONLY



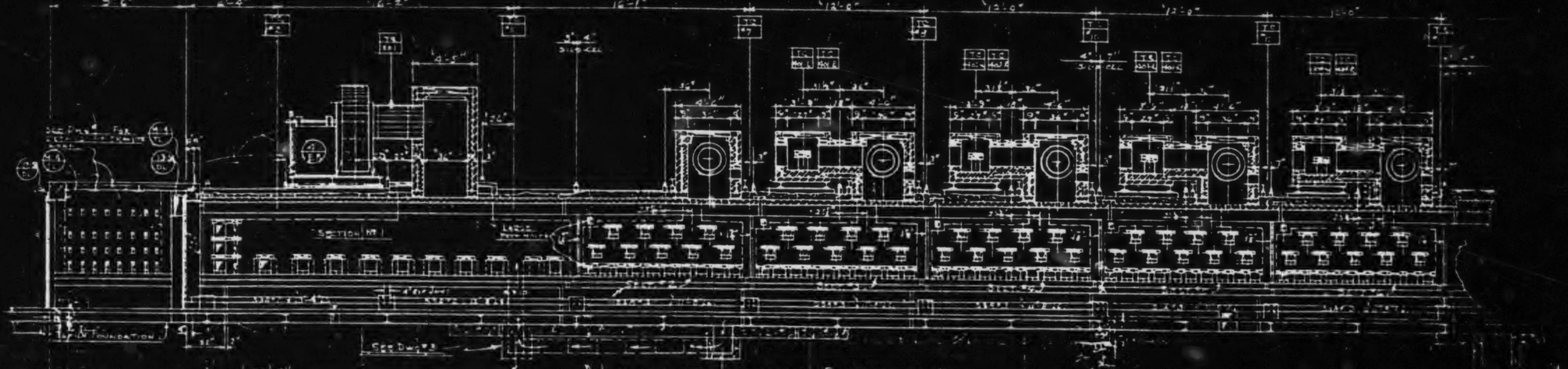
"TYPICAL EXPANSION JOINT No 2"
USED ONLY – IN FIRE ZONE – DWG
FROM HEARTH TO SPRING LINE ONLY



"TYPICAL EXPANSION JOINT No 1"
FROM HEARTH TO SPRING LINE ONLY

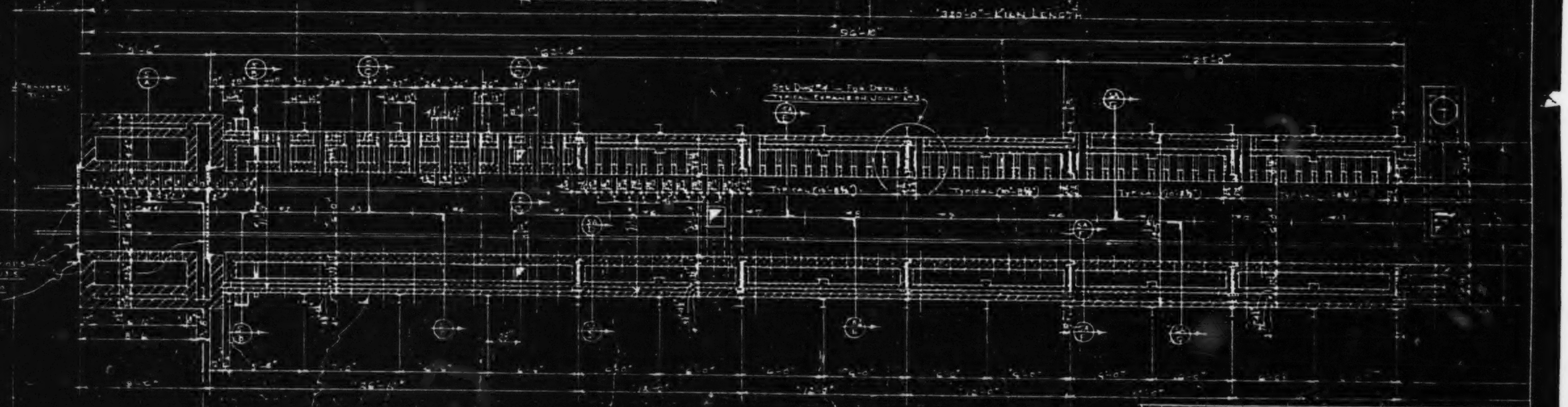


"ELEVATION"



"LONGITUDINAL SECTION"

220'-0" – KILN LENGTH



NOTE
RIGHT SIDE OF SECTION SHOWS WALL CONSTRUCTION ONLY

"PLAN"

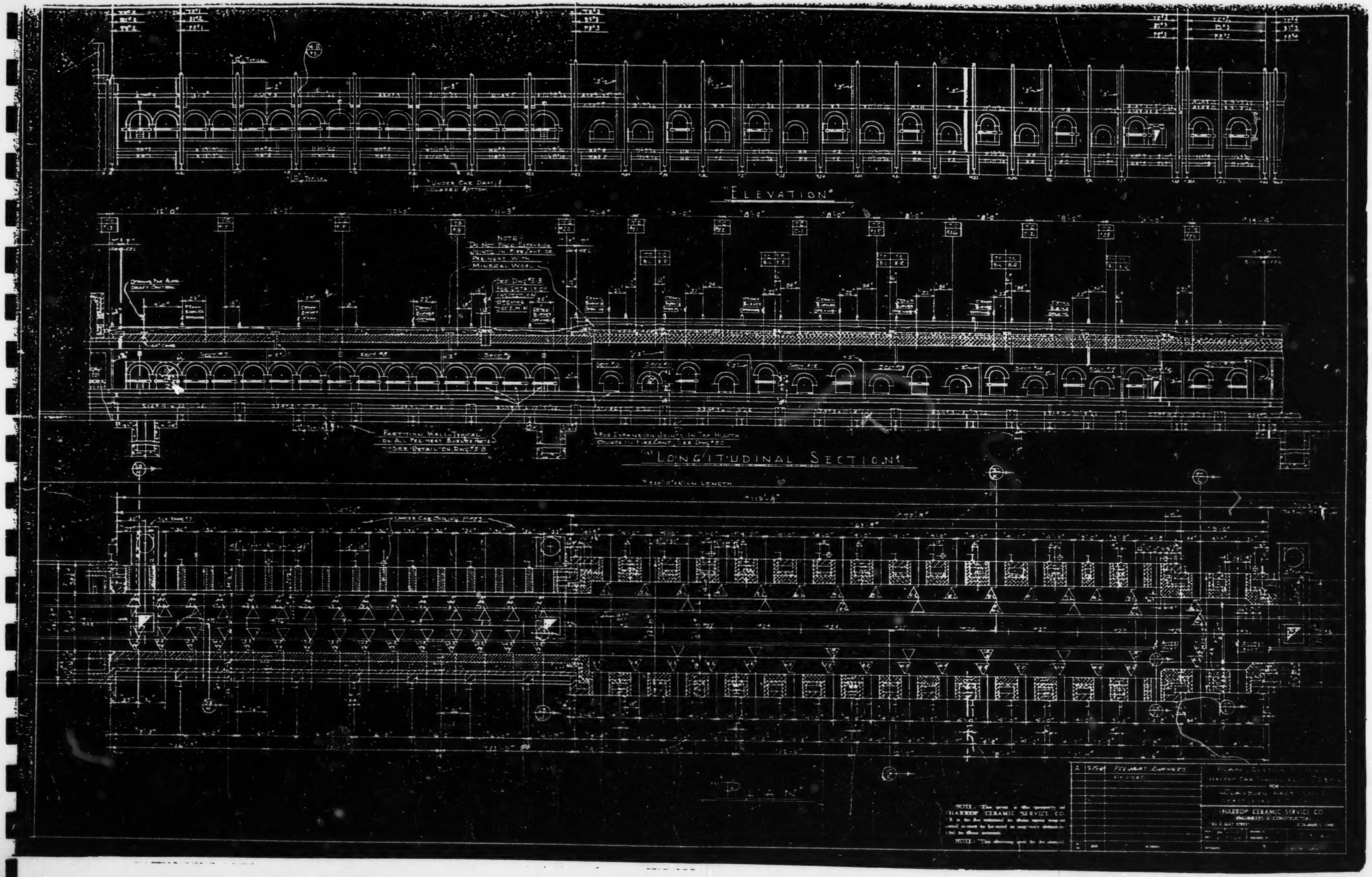
NOTE: This print is the property of HARROP CERAMIC SERVICE CO. It is to be returned to them upon request and is not to be used in any way detrimental to their interests.

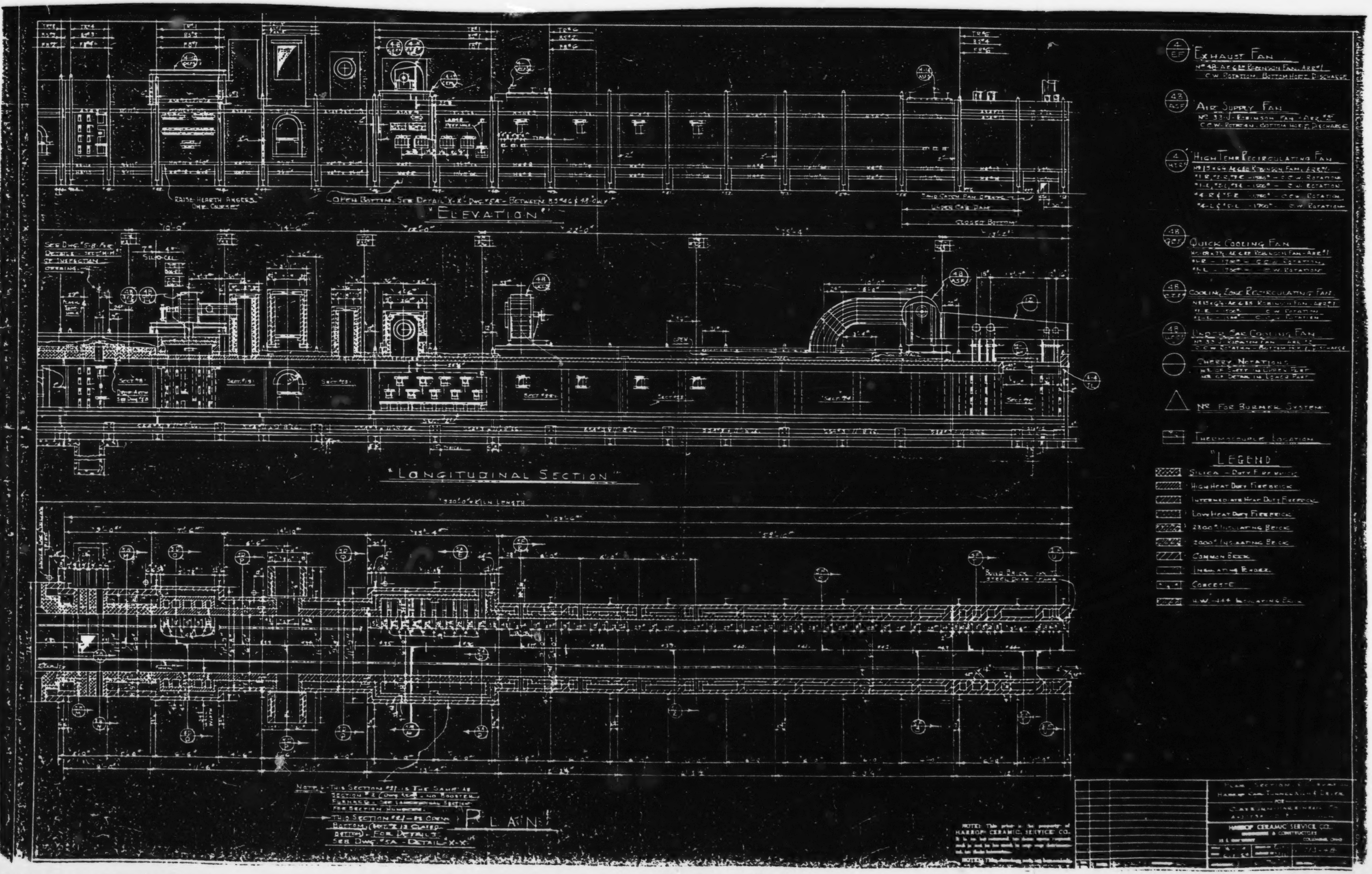
NOTE: This drawing not to be scaled.

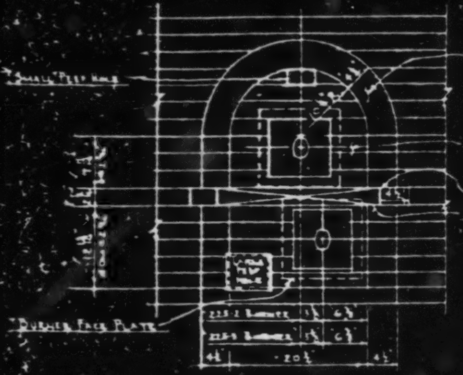
FOR

HARROP CERAMIC SERVICE CO
ENGINEERS & CONSTRUCTORS
35 E. GAY STREET COLUMBUS, OHIO

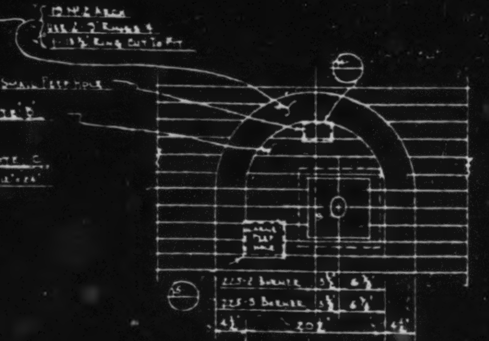
713-4


"ELEVATION"
"UNDER CAR DAMP CLOSED BOTTOM"
NOTE: DO NOT PACK EXPANSION JOINTS IN FIRE ZONE OR PRE-HEAT WITH MINERAL WOOL
SEE DWG #5-B FOR DETAILS OF INSPECTION OPENING
PARTITION WALL-TYPICAL ON ALL PRE-HEAT BURNER PORTS - SEE DETAIL ON DWG #5-B
FOR EXPANSION JOINTS IN TOP HEARTH COURSE IN FIRE ZONE SEE DWG #5-C
"LONGITUDINAL SECTION"
SECT #8
SECT #9
UNDER CAR COOLING PIPES
"PLAN"
A
PRE-HEAT BURNERS
REVISED
HARROP CERAMIC SERVICE CO.
ENGINEERS & CONSTRUCTORS
COLUMBUS, OHIO

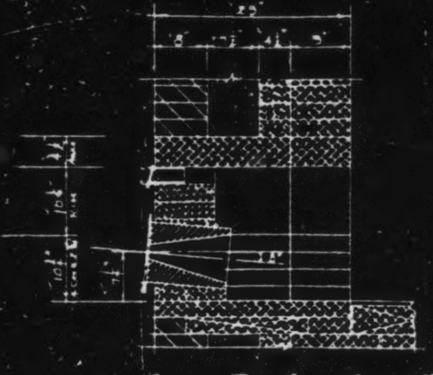
"ELEVATION"
RAISE HEARTH ANGLES ONE COURSE
OPEN BOTTOM. SEE DETAIL "X-X" DWG 5A - BETWEEN
"LONGITUDINAL SECTION"
"330'-0" KILN LENGTH
SEE DWG 5B FOR DETAILS
PLAN
NOTE: THIS SECTION #21 IS THE SAME AS SECTION #2 (DWG ...) NO BOOSTER FURNACES. SEE LONGITUDINAL SECTION FOR SECTION NUMBERS.
THIS SECTION #21 - IS OPEN BOTTOM, (SECT. 2 IS CLOSED BOTTOM) - FOR DETAILS SEE DWG. #5A - DETAIL "X-X"
4 EF — EXHAUST FAN
Nº 48 AE & EB ROBINSON FAN, ARR #1
C.W. ROTATION, BOTTOM HORIZ. DISCHARGE
48 ASF — AIR SUPPLY FAN
Nº 33-J- ROBINSON FAN - ARR. #2
C.C.W. ROTATION, BOTTOM HORIZ. DISCHARGE
4 HTRF — HIGH TEMP RECIRCULATING FAN
Nº 15x64 AE & EB ROBINSON FAN, ARR #1
#1-R, #2-R, #3-R - 1500° - C.C.W. ROTATION
#1-L, #2-L, #3-L - 1500° - C.W. ROTATION
#4-R & #5-R - 1700° - C.C.W. ROTATION
#4-L & #5-L - 1700° - C.W. ROTATION
48 QCF — QUICK COOLING FAN
Nº 68x7½ AE & EB ROBINSON FAN - ARR #1
#1-R - 1700° - C.C.W. ROTATION
#1-L - 1700° - C.W. ROTATION
48 CZRF — COOLING ZONE RECIRCULATING FAN
Nº 15x64 AE & EB ROBINSON FAN - ARR #1
#1-R - 1500° - C.W. ROTATION
#1-L - 1500° - C.C.W. ROTATION
48 UCCF — UNDER CAR COOLING FAN
Nº 33 J. ROBINSON FAN - ARR #2
C.C.W. ROTATION - BOTTOM HORIZ. DISCHARGE
CHERRY NOTATIONS
Nº OF SHEET IN UPPER PART
Nº OF DETAIL IN LOWER PART
Nº FOR BURNER SYSTEM
THERMOCOUPLE LOCATION
"LEGEND"
SILICA - DUTY FIREBRICK
HIGH HEAT DUTY FIREBRICK
INTERMEDIATE HEAT DUTY FIREBRICK
LOW HEAT DUTY FIREBRICK
2300° INSULATING BRICK
2000° INSULATING BRICK
COMMON BRICK
INSULATING BLOCK
CONCRETE
H.W. 444 INSULATING BRICK
PLAN, SECTION & ELEVATION
HARROP CAR TUNNEL KILN & DRYER
FOR
HARROP CERAMIC SERVICE CO.
ENGINEERS & CONTRACTORS
COLUMBUS, OHIO
NOTE: This print is the property of HARROP CERAMIC SERVICE CO.
73-48



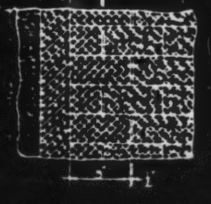
FRONT VIEW DOUBLE BURNER PORT



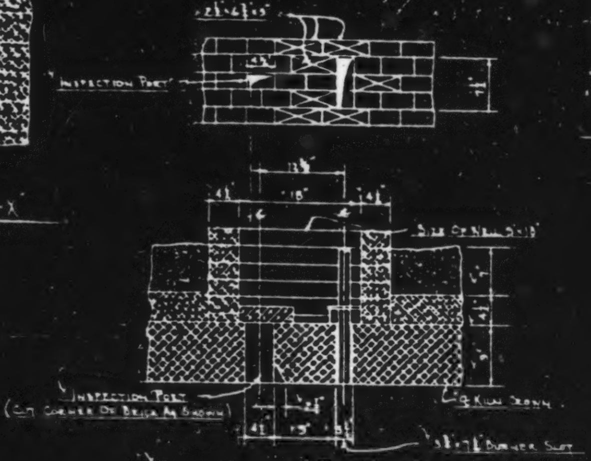
FRONT VIEW SINGLE BURNER PORT



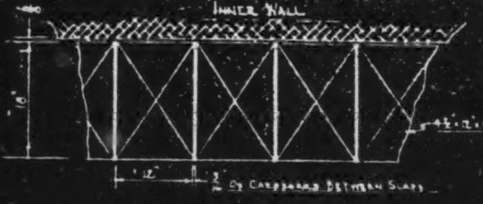
SECTION THRU SINGLE BURNER PORT



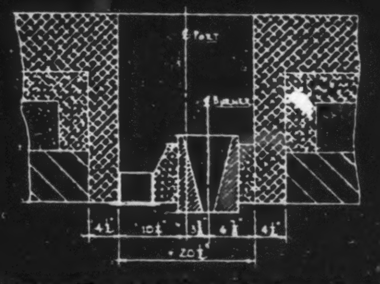
SECTION X-X



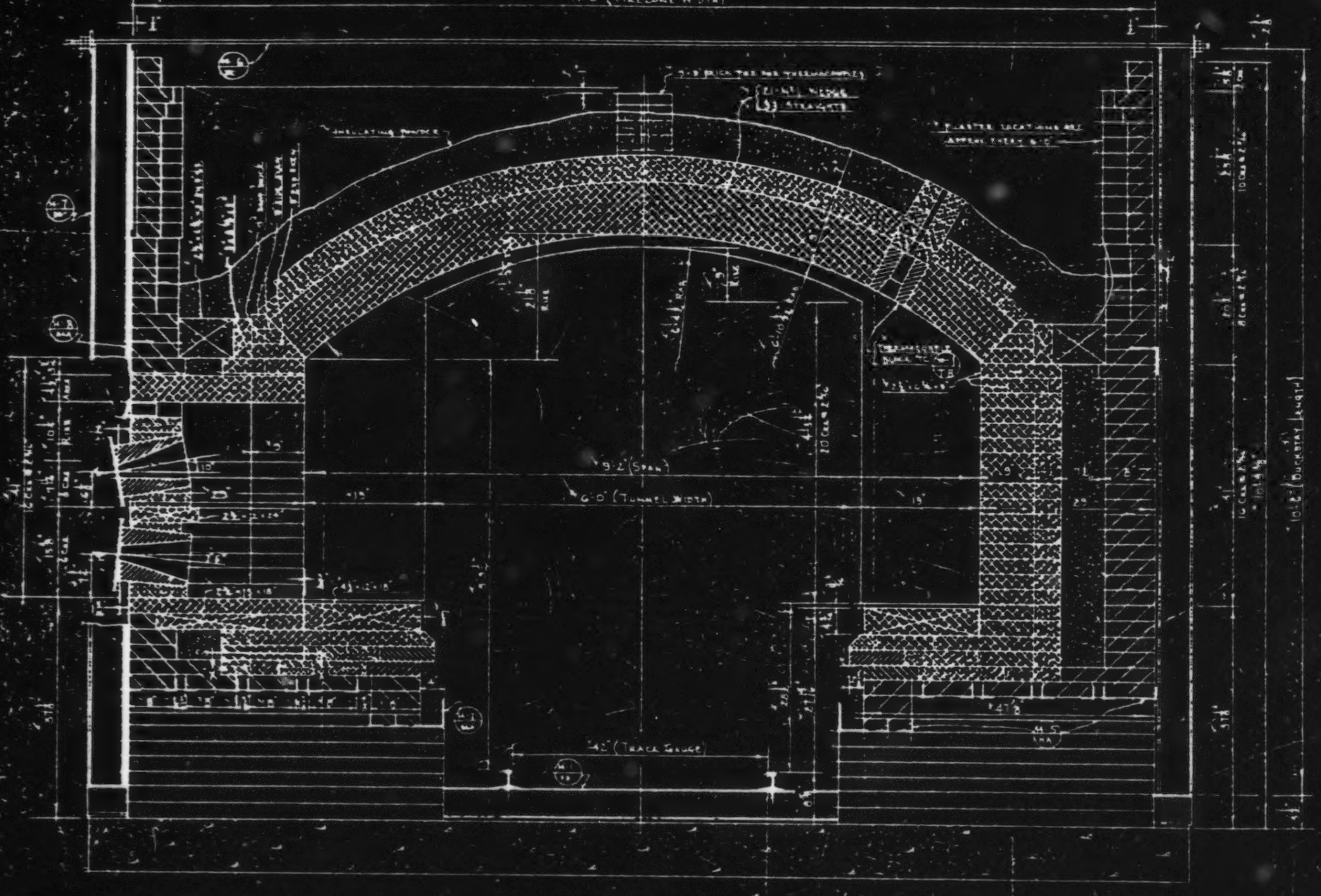
CROWN BURNER & PEEP HOLE DETAIL



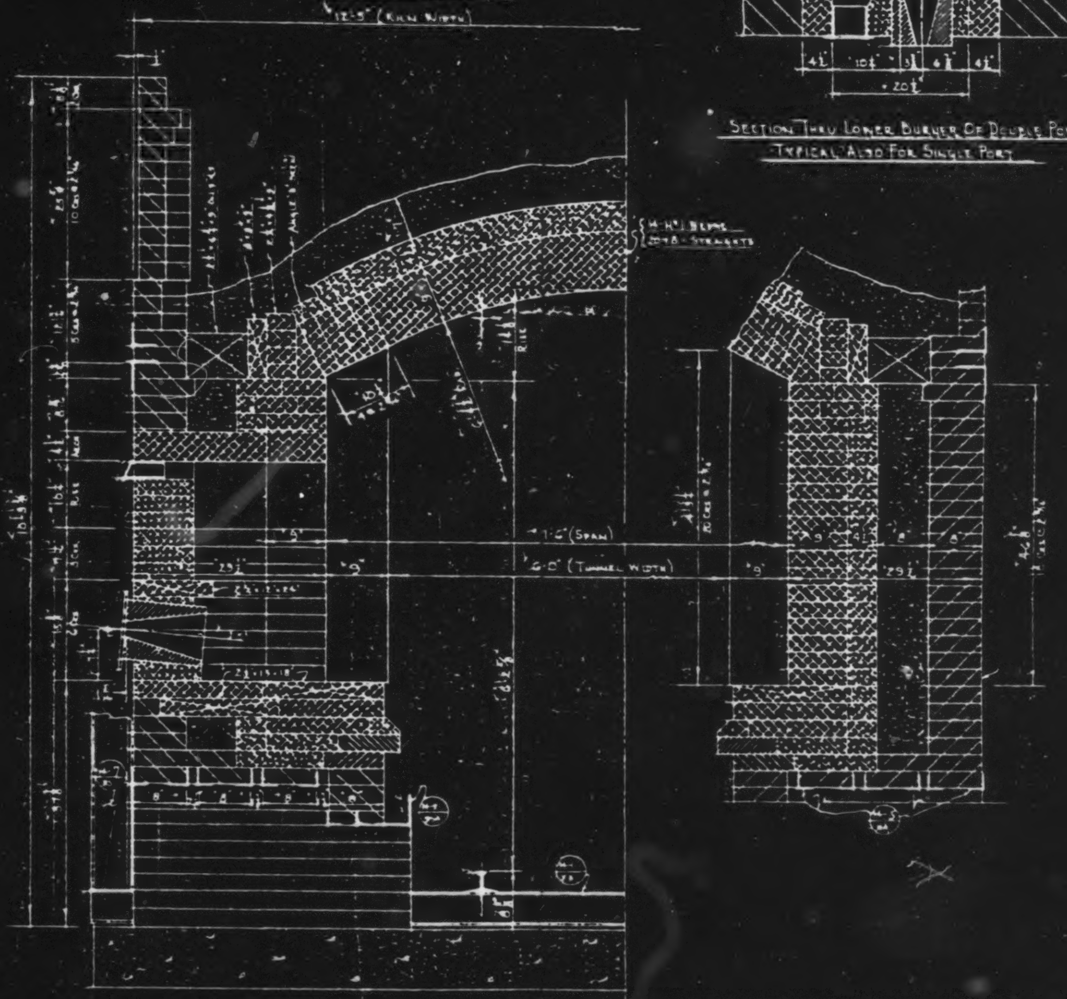
PLAN VIEW OF HEARTH SLABS



SECTION THRU LOWER BURNER OF DOUBLE PORT
TYPICAL ALSO FOR SINGLE PORT



SECTION K-K



SECTION 1-1

NOTES

(A) In All Cases Burner Blocks Are Toward The Charging End & Peep Holes Are Toward The Discharge End.

(B) Insulating Brick To Be Laid Without Mortar Then Plaster Outside With Mortar.

(C) ⅛" Cardboard To Be Placed Around Each End Of Slabs. Use No Mortar. Slab To Be Free On Both Ends For Removal.

LEGEND

▨	Silica Brick
▨	High Heat Duty Firebrick
▨	Intermediate Duty Firebrick
▨	Low Heat Duty Firebrick
▨	Common Brick
▨	[illegible] Insulating Brick
▨	2600°F Insulating Brick
▨	2300°F Insulating Brick
▨	2000°F Insulating Brick
▨	Insulating Powder
▨	Concrete

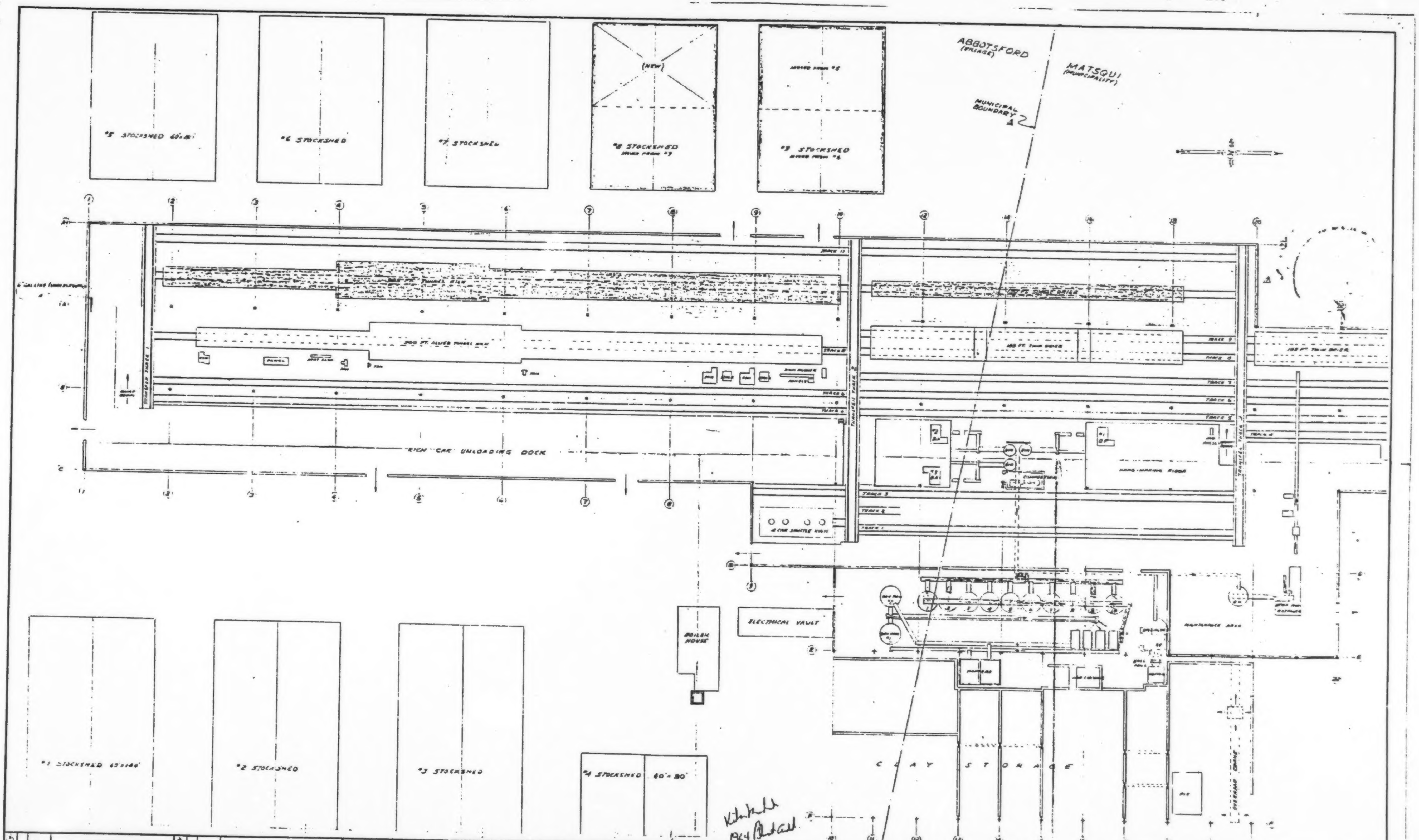
NOTE: This print is the property of HARROP CERAMIC SERVICE CO. It is to be returned to them upon request and is not to be used in any way detrimental to their interests.

NOTE: This drawing [illegible]

Firezone Sections
Harrop Car Tunnel Kiln Furnace
For
Clayburn-Harbison Co.
Abbotsford B.C. Canada

HARROP CERAMIC SERVICE CO.
ENGINEERS & CONSTRUCTORS
[illegible] E. Gay Street
Columbus, Ohio

[illegible]



Kiln Replaced
1964 Plant Addl.

NO	BY	DATE	REVISION
4			
3			
2			ADDED MUNICIPAL BOUNDARY
1			NO. 15 KILNS LONG ... COL LINES 1-12

DWG NUMBER | REFERENCE DRAWINGS

CLAYBURN - HARBISON LTD.
P.O. BOX 160
ABBOTSFORD, B.C. CANADA

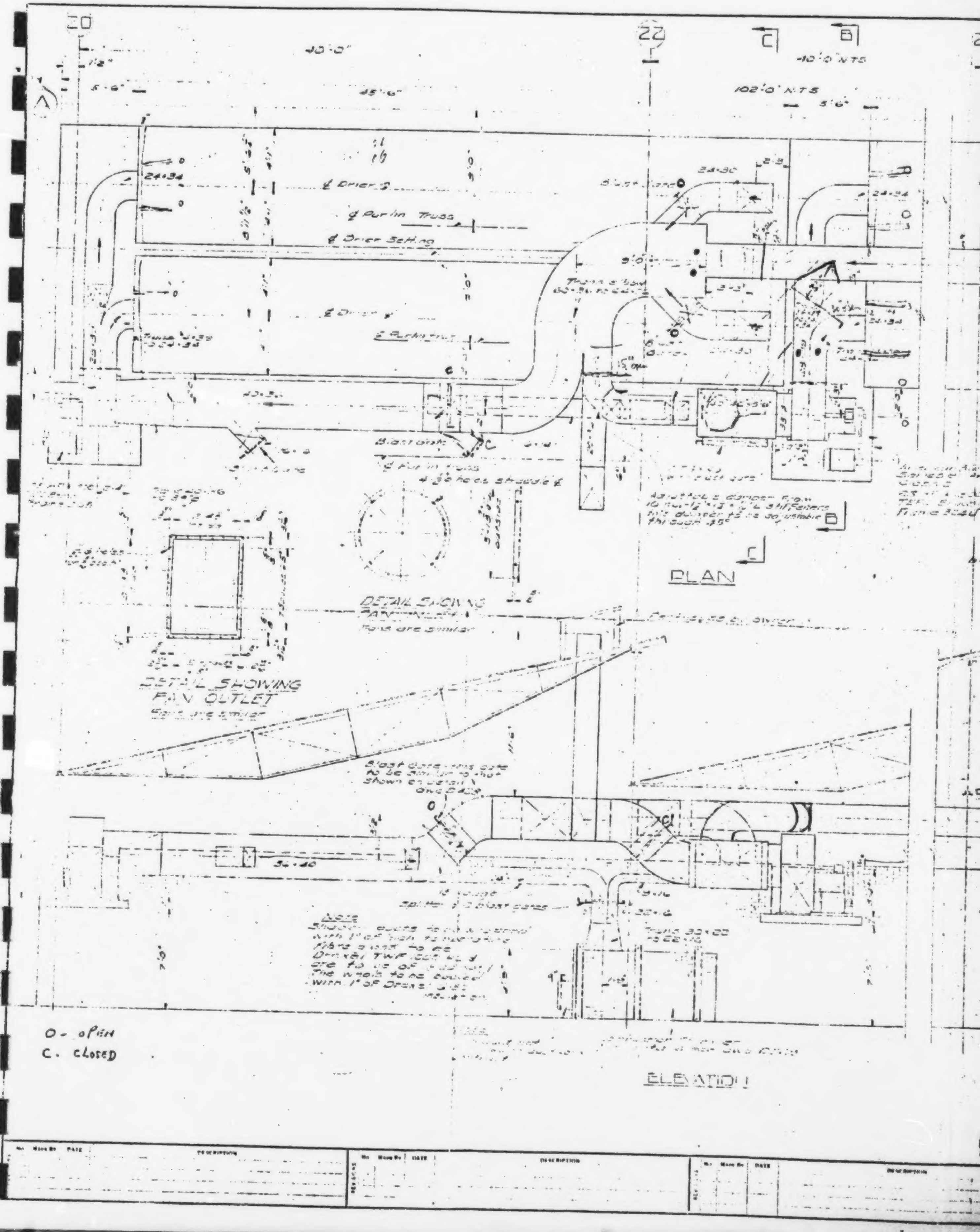
THIS DRAWING CERTIFIED FOR CONSTRUCTION BY:
DATE ISSUED

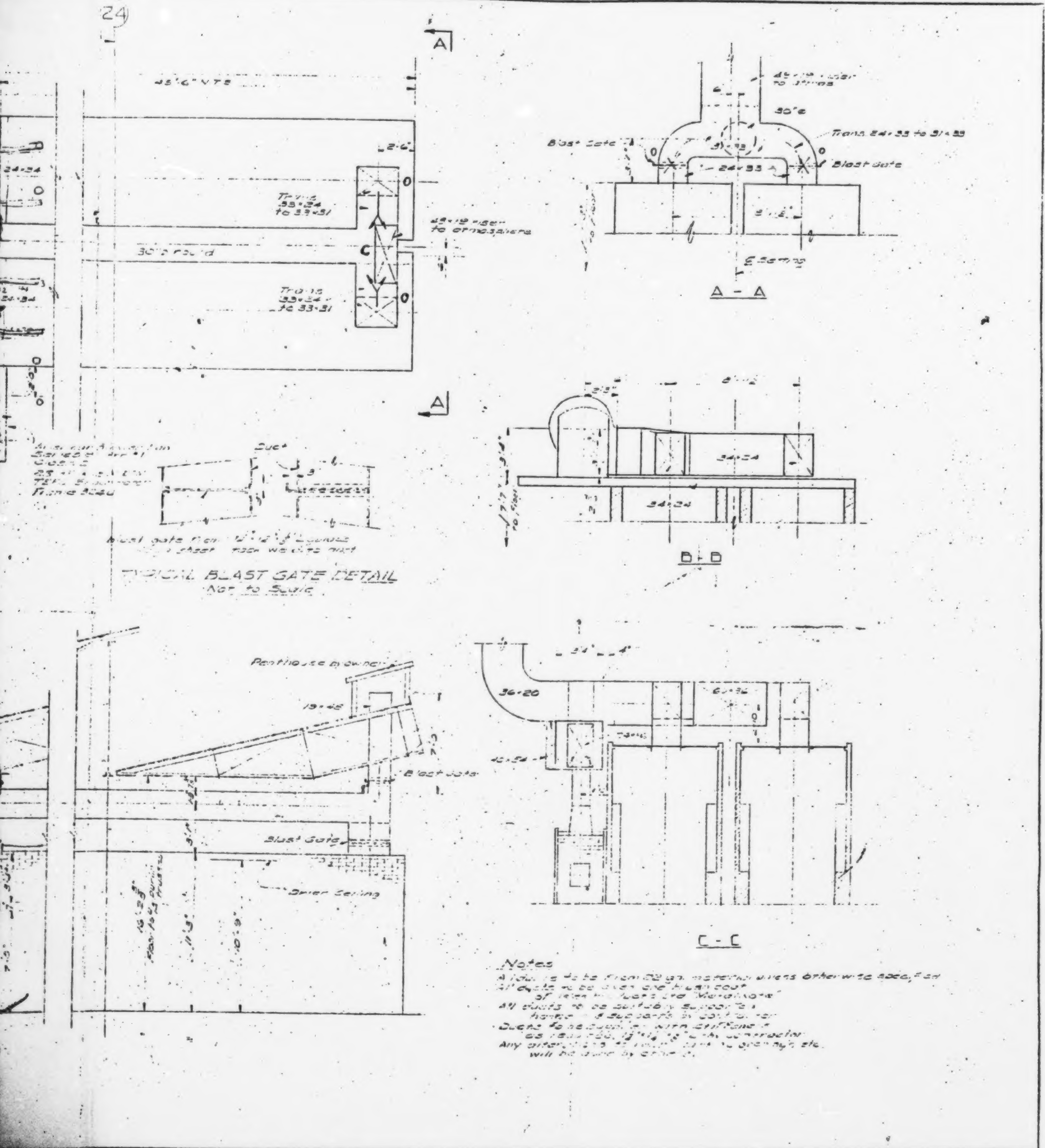
DRAWN BY Harper 12 2 64
CHECKED BY
APPROVED BY

PLANT No 2 ABBOTSFORD DEPT PLANT ENGINEERING
FOR NEW WORK SHOWN SHADED
TITLE PLANT EXPANSION - 1964

SCALE 1" = 20'-0"
DRAWING NUMBER D- 613 - 2

APPENDIX G - STIFF MUD PREDRYER DRAWINGS

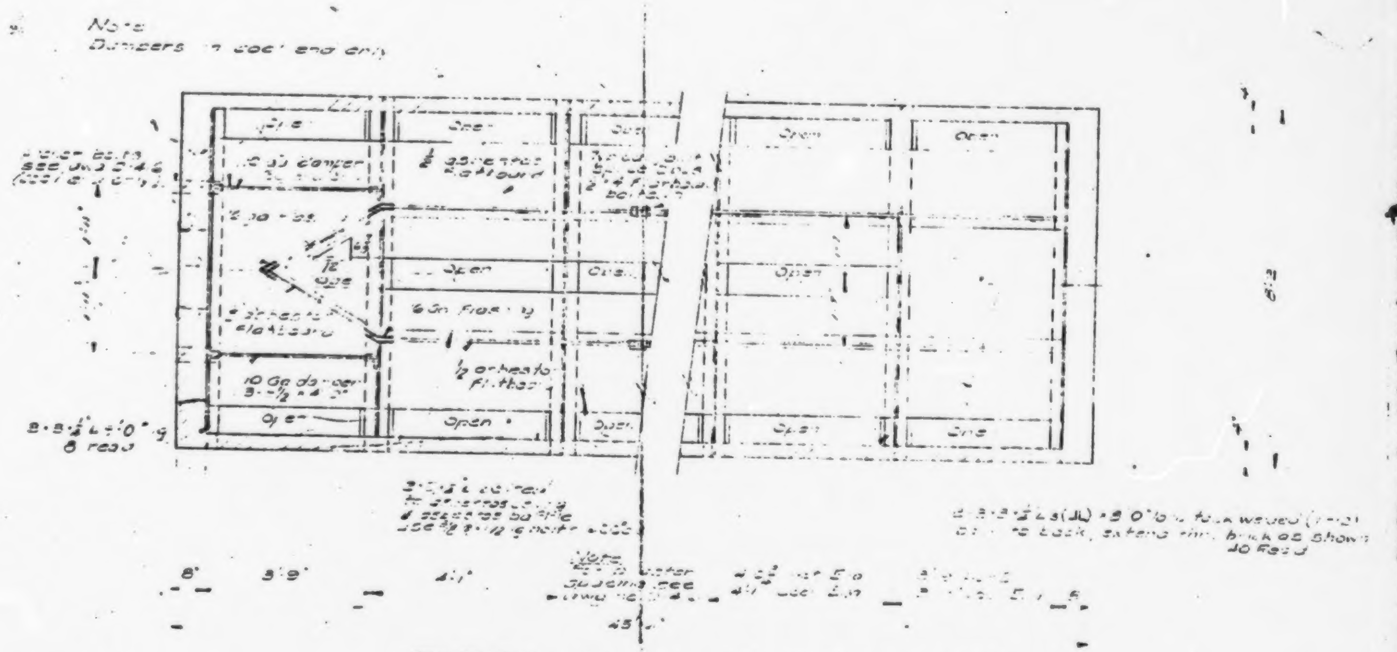
20
22
C
B
40'-0"
40'-0" N.T.S.
102'-0" N.T.S.
1/2"
6'-6"
45'-6"
5'-6"
24×34
24×30
24×34
℄ Drier 3
℄ Purlin Truss
℄ Drier Setting
℄ Drier 4
℄ Purlin Truss
Blast Gate
Trunk elbow
2'-3"
15" dia.
Blast Gate
4-3/8 holes straddle ℄
Adjustable damper from
10 ga. with 1 1/2 × 1 1/2 × 1/4 L stiffeners
this damper to be adjustable
thru 35°
PLAN
DETAIL SHOWING
FAN INLET
Fans are similar
DETAIL SHOWING
FAN OUTLET
Fans are similar
Blast Gate - this gate
to be similar to that
shown on detail
O
C
36×40
16 gauge
Splitter & 2 blast gates
Trunk 30×22
to 22×16
Note
Sheet metal ducts to be insulated
with 1" of high temperature
fibre glass to be
Drexel TWF 1000 and
are to be of
The whole to be covered
with 1" of Drexel
9"
ELEVATION
O - OPEN
C. CLOSED
No. Made By DATE DESCRIPTION
No. Made By DATE DESCRIPTION
No. Made By DATE DESCRIPTION
REVISIONS



Notes
All ducts to be from 22 ga. material unless otherwise specified
All ducts to be given one brush coat of [illegible]
All ducts to be suitably supported, hangers & supports by contractor
Ducts to be supplied with stiffeners as required, [illegible] by contractor
Any alterations to [illegible] etc. will be done by [illegible].

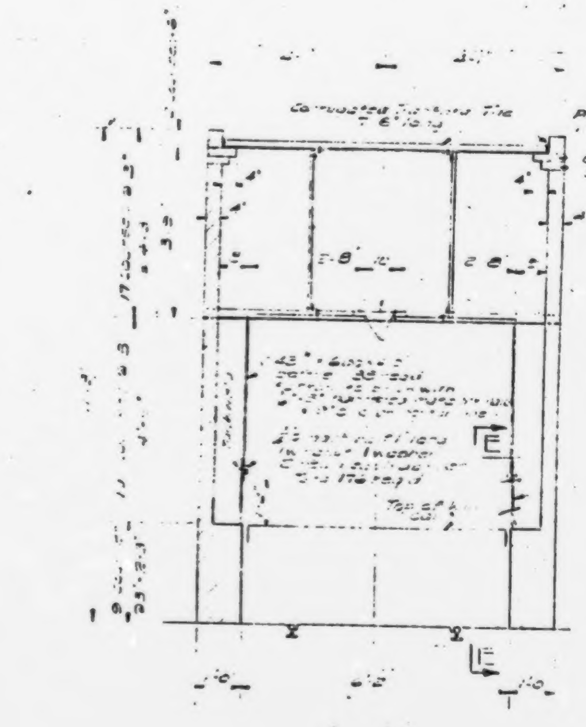
DRAWN BY [illegible]	PLANT [illegible] ABBOTSFORD	**CLAYBURN COMPANY LTD.** P. O. BOX 160 ABBOTSFORD, B. C.
TRACED BY	DEPT [illegible]	SCALE [illegible]
CHECKED BY H Bork Jan 28/67	[illegible] SECONDARY [illegible]	DATE ISSUED
APPROVED BY [illegible] Jan 28/67	[illegible]	DRAWING NUMBER D-527

Note:
Dampers in cool end only

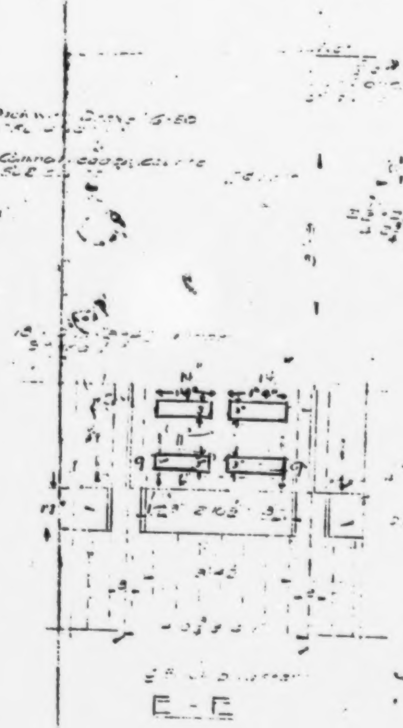


TYPICAL PLAN AT ELEV 103'-0"

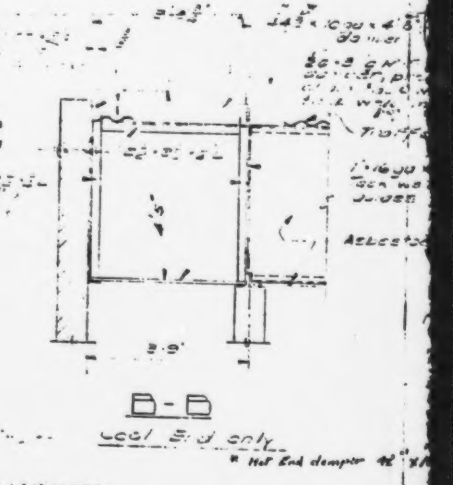
Cool End shown Hot End as Noted



A-A



E-E



B-B

Cool End only

* Hot End damper 42" x

BAR S

Mk No	Size	No Req'd	Length	#5	#4
217-1	#5	33	12' 6"		
217-2	#4	–	–		534
217-3	#5	16	6' 0"	96	
217-4	#5	16	6' 9"	107	
Length in feet				203	534
Weight in pounds				77	357

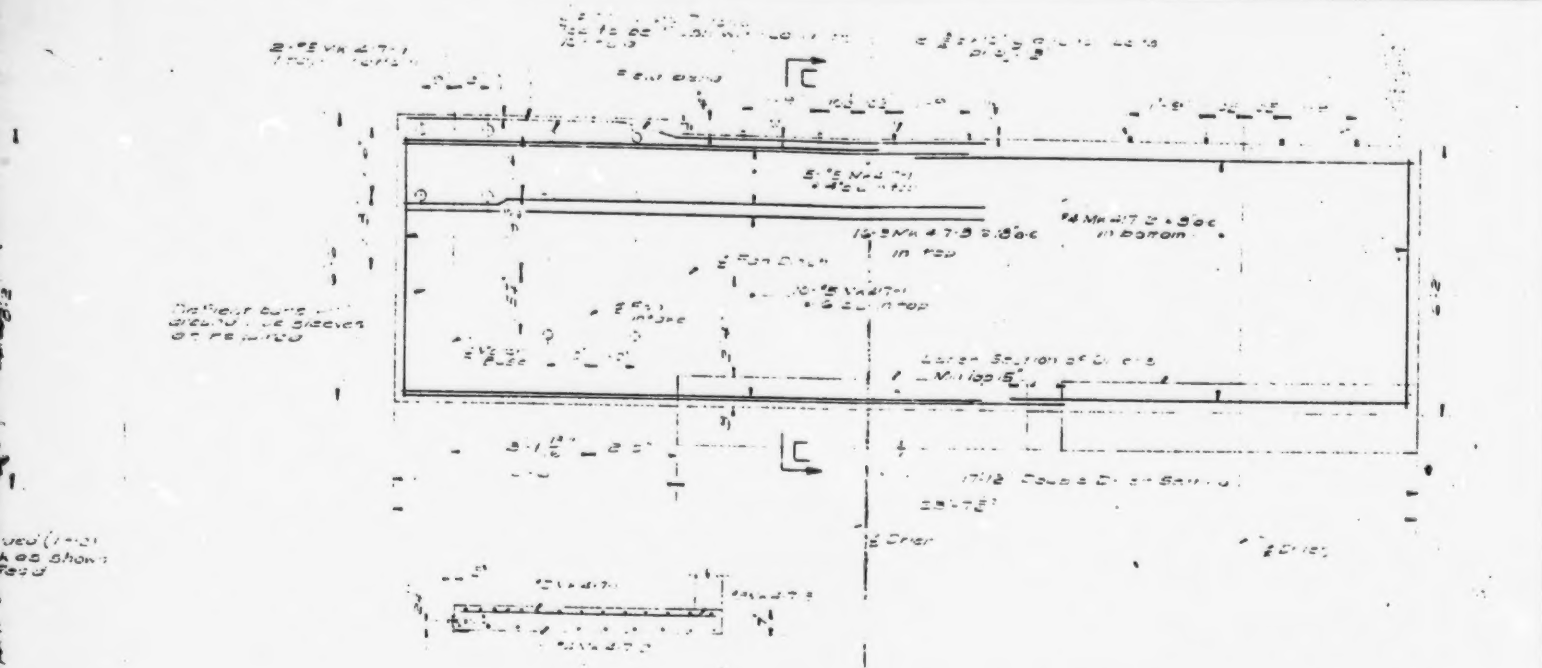
No.	Made By	DATE	DESCRIPTION

REVISIONS

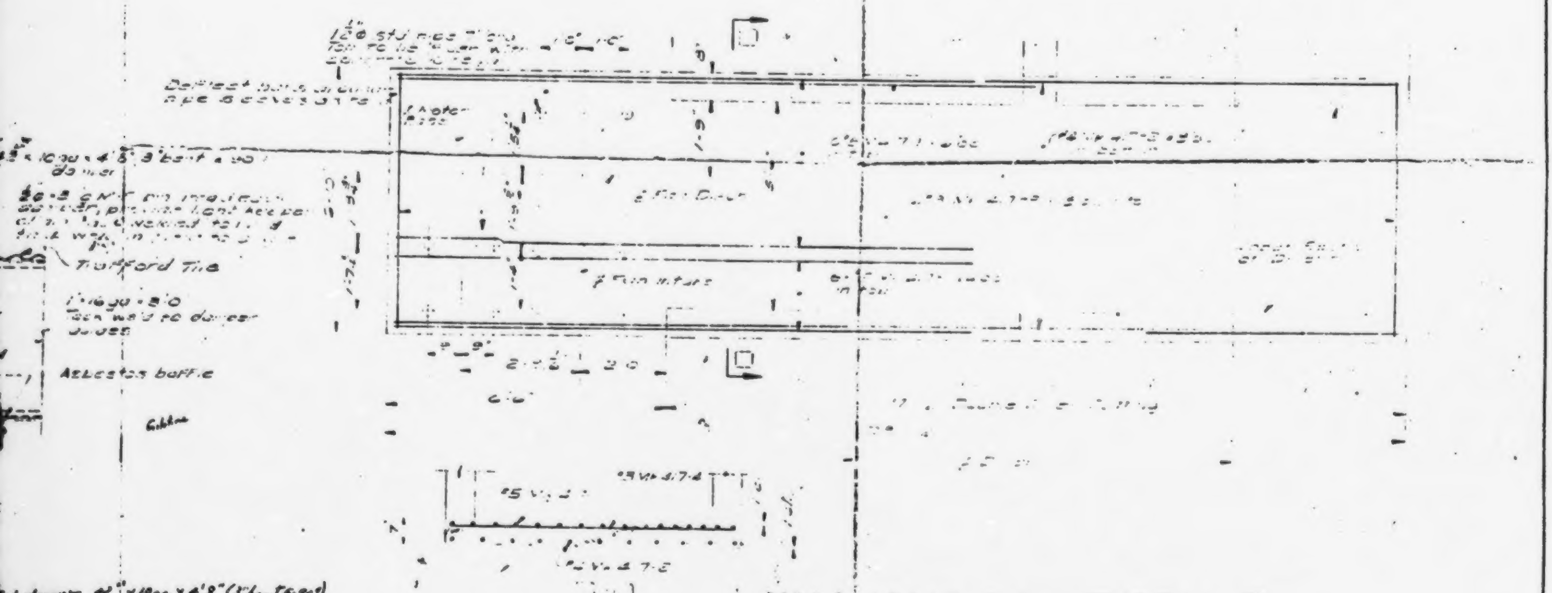
No.	Made By	DATE	DESCRIPTION

REVISIONS

No.	Made By	DATE	DESCRIPTION



C-C FAN PAD #1 - DETAILS



Rod damper 42" x 10ga x 4'8" (3" bent @ 90°)

D-D FAN PAD #2 - DETAILS

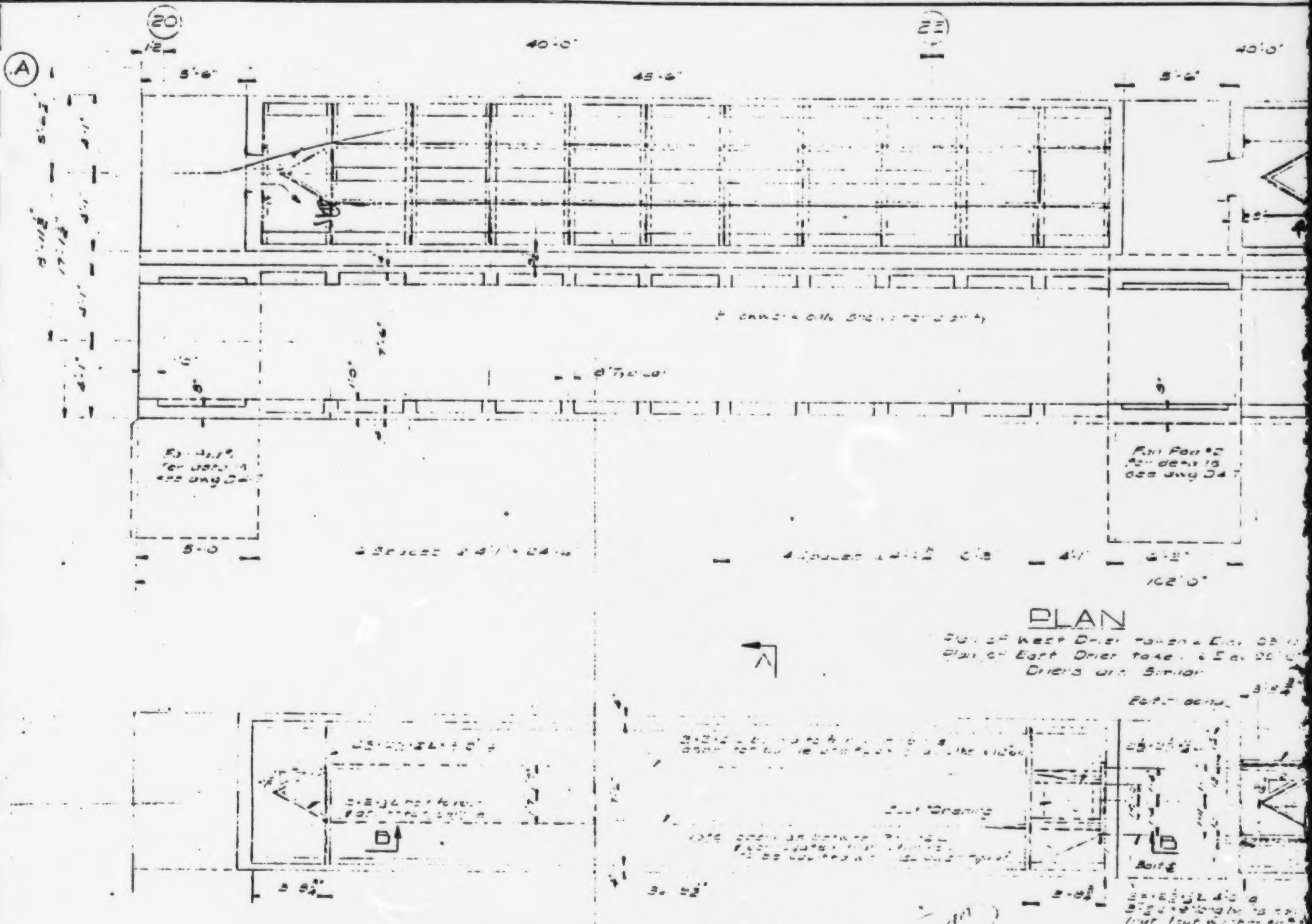
Notes

BAR SCHEDULE

Leng	#3	#4	#5	Description
13'-6"			1460	Straight
-		534		[illegible]
6'-9"	96			Straight
-9	107			"
et	203	534	646	
nds	77	357	466	Total weight 900 lbs

DRAWN BY Shulinga C.T. Fe	PLANT #2 ABBOTSFORD	SCALE ¼" = 1'0"
TRACED BY	DEPT BURNING	DATE ISSUED
CHECKED BY M.H.P. Mar. 1956	102'-0" SECONDARY DRIER	DRAWING NUMBER D-417
APPROVED BY R.P.G. Mar 26/56	DETAILS SHEET #2	REV. 0

CLAYBURN COMPANY LTD.
P. O. BOX 160 ABBOTSFORD, B. C.

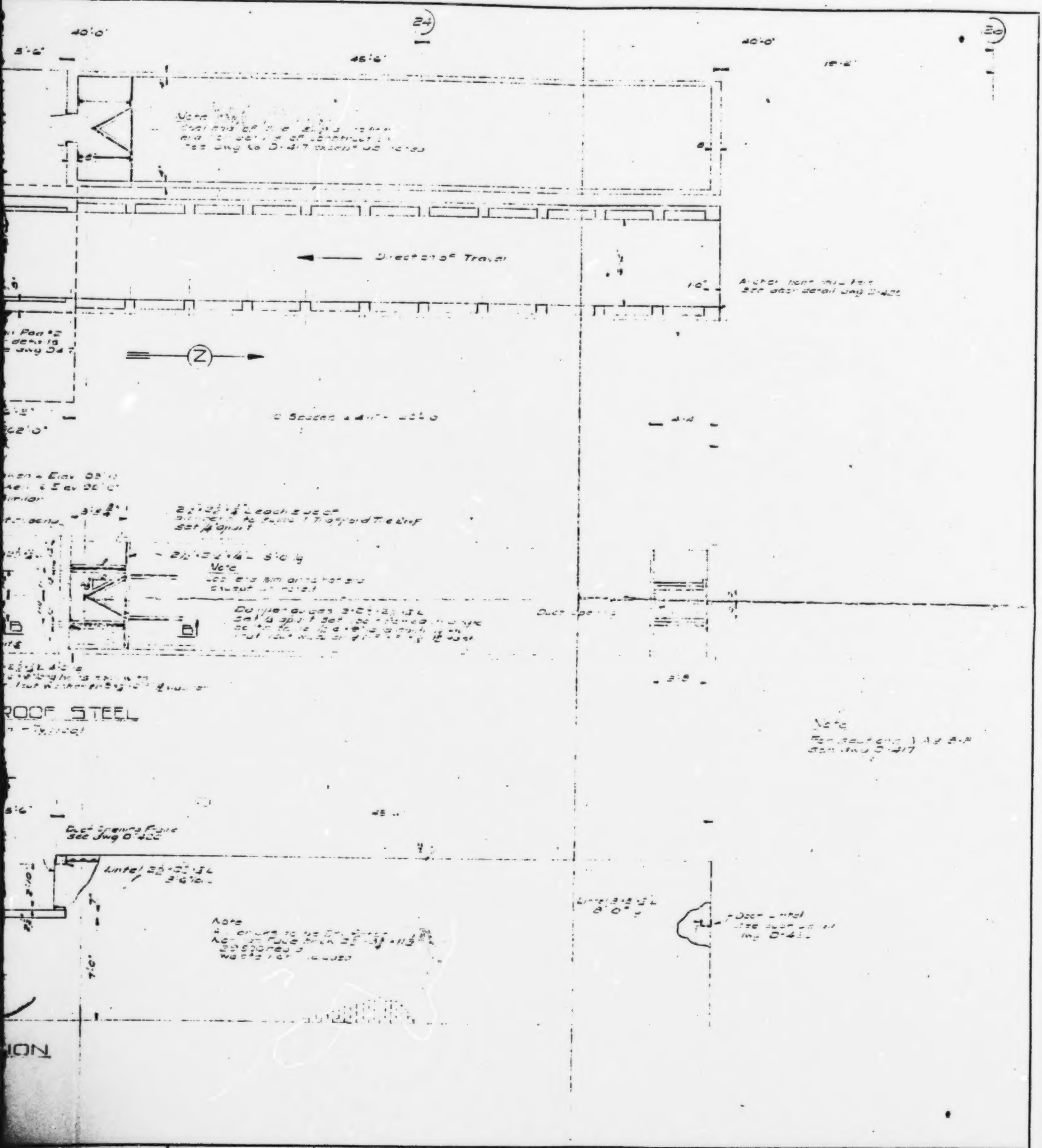


A
20
22
1'2"
40'-0"
40'-0"
5'-6"
45'-6"
5'-6"
5'-0"
4'-1"
6'-2"
162'-0"
Fan Pad #1 For details see Dwg D-47
Fan Pad #2 For details see Dwg D-47
8" Typical
PLAN
Plan of West Drier taken @ Elev.
Plan of East Drier taken @ Elev.
Driers are Similar
Bott. Bend
Duct Opening
B
Bolt ℄
3'-8¾"
2'-8¾"
A
PLAN OF ROOF STE
West Drier Shown - Typical
5'-6"
45'-6"
5'-6"
Duct Opening Frame See Dwg D-420
Elev. 24'-6"
Lintel
Finished Floor @ Elev. 95'-9
ELEVATION

No	Made By	DATE	DESCRIPTION

No	Made By	DATE	DESCRIPTION

No	Made By	DATE	DESCRIPTION



DRAWN BY	PLANT	**CLAYBURN COMPANY LTD.**	SCALE	
TRACED BY	DEPT Burning	P. O. BOX 160 ABBOTSFORD, B. C.	DATE ISSUED	
CHECKED BY	Secondary Drier		DRAWING NUMBER D-416	REV 0
APPROVED BY	Detail Sheet #1			

APPENDIX H - BICKLEY SHUTTLE KILN AND DRYER DRAWINGS

BICKLEY FURNACES INC.

550 STATE ROAD • P. O. BOX 6069 • PHILA., PENNA. 19114
TEL. 215/638-4500 • TELEX: 83-4310 • CABLE: BICKLYFURN

October 24, 1985

KENT ENGINEERING
475 Gordon Ave.
W. Vancouver, BC, Canada V7T 1R7

Attn: Mr. Clarence Kent

Dear Mr. Kent:

In reference to our recent telephone conversation, I am enclosing a few technical papers which have been prepared by Bickley over the past few years which illustrate general kiln improvements that have been directed towards better fuel economies. Efforts to obtain reduced fuel consumptions are continual at Bickley and, as you will note from the enclosed articles, substantial reductions have been achieved.

Enclosed also are a few photos illustrating fiber lined shuttle kilns which are becoming more of a standard on a majority of our installations. The extremely low heat storage of fiber when compared to dense or insulating firebrick makes this an excellent material for periodic operations. The major benefits are seen in the very rapid cycles which may range from 8 to 20 hours on a cold-to-cold basis.

In addition to the extended use of fiber materials, Bickley has incorporated many heat recovery systems on our newer shuttle kilns. This recovery is normally through a stack/convection type recuperator which recovers heat from the products of combustion during the firing cycle. These clean gases may be introduced back into the kiln as preheated combustion air, or may be used alternately as required throughout the plant. Normally the preheated combustion air is introduced back into the burners at a temperature in the range of 500°F.

I have also enclosed a photo to illustrate the significant improvements made in instrumentation and in general automation in the past several years. With microprocessor controllers, Bickley has been able to regulate very closely the amount of excess air entering the kiln. By introducing excess air only where definietly necessary during the heating cycle, we are able to make substantial reductions in fuel consumption. On many of our shuttle kilns, the amount of air is programmed throughout the cycle in the same manner the temperature profile is followed.

I trust this general information plus the enclosed photos and articles will be of assistance to you in your report. I would appreciate your contacting me should you learn of any possible kiln requirements in your area.

Sincerely,

BICKLEY FURNACES INC.

Samuel J. Tricase
Vice President

SJT:dlm

Encl.: J-6, 25th Anniv. ad,
Bickley Bulletin (Sept. 1985),
"Scientific Kiln Management",
Photos: 3281-C, 3282-C

BICKLEY FURNACES W.H., INC.
P. O. BOX 6069 · PHILA., PENNA. 19114 · TEL. 215/636-4500 · TELEX: 83-4310 · CABLE: BICKLYFURN

November 6 , 1978

File No. 3474 -R1

Clayburn Industries Ltd.
Railway & Pine
Abbotsford, B.C., CANADA V2S 5C1

QUOTATION

BICKLEY MODEL 5100 ISO→JET SHUTTLE KILN SYSTEM

PART 1.0 - SHUTTLE KILN BASIC SPECIFICATIONS

Product: A. High Alumina Refractories and Giant Brick,
4, 6, 8 and 12" widths and 4" x 16" face. 203,000 lbs

101 tons

Kiln Capacity: 75 tons at 94 lbs./cu. ft. (128 lbs/cu ft.) CB 76 D

Useable Setting Volume: 1600 cu. ft.

72 MAX x 54" MAX

Setting Dimensions Per Car: 68" wide x 70" long x 48" high 7-3"

4-0
0+6" sides
+4" clearance

Number of Cars in Kiln: 12 (2 wide x 6 long)

Maximum Use Temperature: 2550° F

Type Combustion System: 21,000,000 BTU/hr.

Number of Burners: 14 (7 per level)

Number Automatic Temperature Zones of Control: six (6)

6-9" from floor

Kiln Cycle Time (cold to cold): 54 hours to 168 hours

Fuel: Natural gas

846 Brick/car

PART 5.0 - Dryer

One Bickley 2 track batch dryer will be supplied to remove up to 5% moisture from pressed brick which have been set on kiln cars. Twelve (12) cars are moved into the dryer at one time. The dryer then starts a drying cycle which will normally be equal to or less than the time for the firing cycle.

The dryer is constructed of masonry sidewalls and insulating concrete roof. The doors will be constructed of insulated panels, manual sliding to one side. Two fans will be provided. A supply fan will pull hot air from either the kiln, or the make-up combustion chamber and blow into a manifold duct along the dryer. From the duct the hot air is distributed to alternate firelanes of the setting on the cars.

The exhaust fan will pull air out of the dryer from alternate firelanes and discharge into a stack. The stack will extend thru the roof and be equipped with a weather hood. The purchaser must provide an opening in the roof and flash around the stack after is is installed.

The dryer is designed to operate either on waste heat from the shuttle kiln or from a make-up burner or a combination of both. The make-up burner will be equipped with pilot, manifold piping, combustion air fan and safety equipment.

price page 10 The insulated waste heat duct from the kiln exhaust fan to the dryer is not included as part of the dryer system price. (gas to burner)

The dryer will have thermometers to determine the input and output temperatures. Dampers will be manually set to obtain the proper temperatures and flow thru the dryer for the best drying cycle.

Bickley will furnish the complete design of the dryer. This will include construction drawings for the masonry walls, roof, doors and ductwork that will be supplied by the purchaser. Bickley will furnish the necessary fans, drives, motors and starters, dampers and combustion equipment for the dryer.

PRICE. $18,400.00

OK
check
with
Chuck

max. 18 HR'S.
320°

PART 1.0 - Shuttle Kiln Basic Specifications - Continued

Power Voltage: 460 Volt, 3 phase, 60 hertz ✓

Number of Doors: ~~One~~ Two

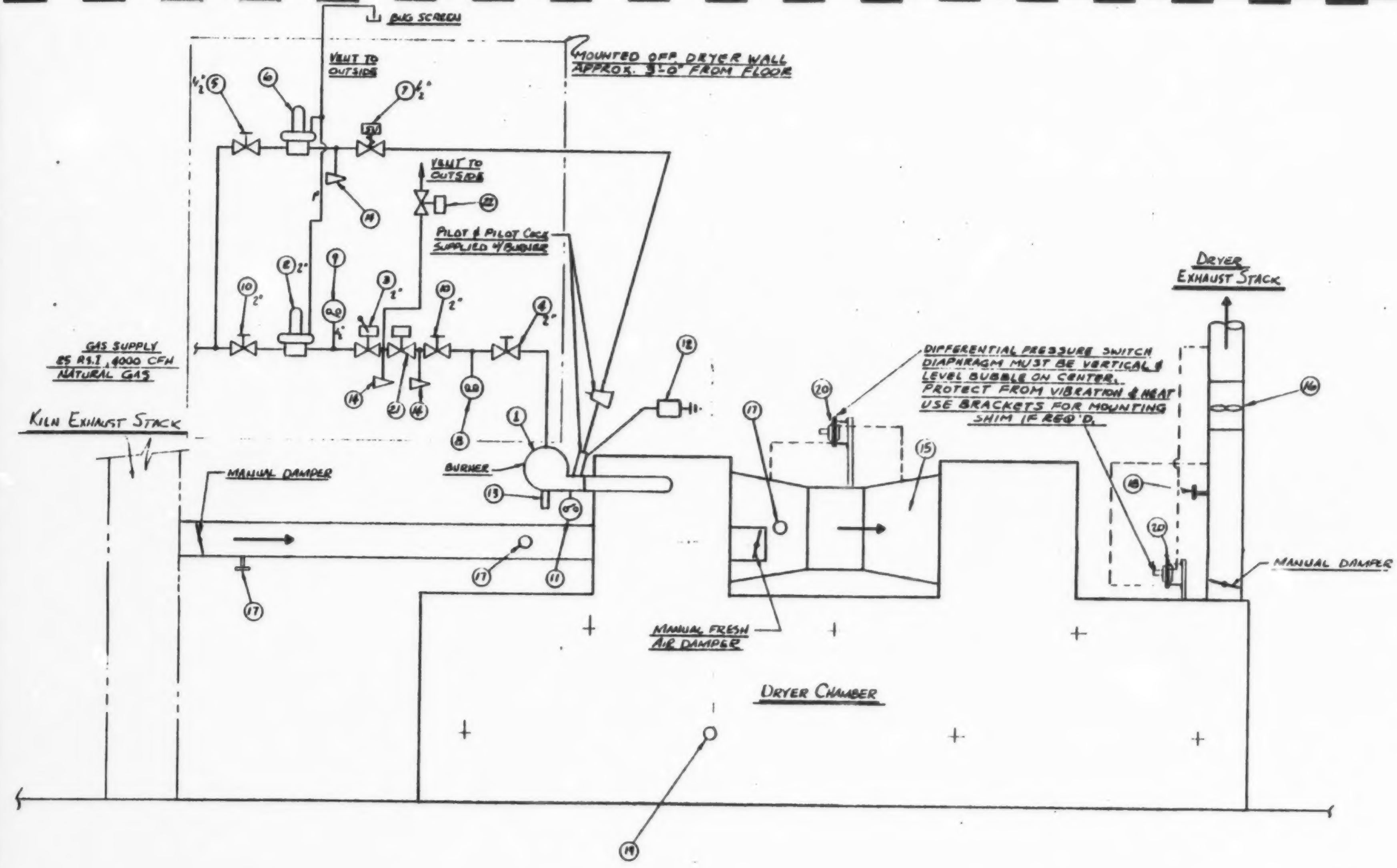
Type of Door: ~~Vertical~~ Lift sliding

PART 2.0 - Shuttle Kiln Design

Item 2.01 - Construction

The kiln is constructed with a thick steel casing which is reinforced with structural steel. The kiln is lined with 11" of refractory material including 9" of 2800°F insulating brick on the hot face backed up with 2 layers of 6 pound density Kaowool blanket insulation. The two layers are to be 1-1/2" and 1" respectively, compressed down to 2" thick when installed. The refractory walls are held tight against the steel casing by a system of alloy steel anchors. The anchors are installed on multiple levels and allow the refractory walls freedom to expand and contract thereby greatly increasing the life of the refractories. The refractory arch is a flat, suspended arch using refractory "I" beam tiles and metal hangers with a topping layer of 2 inches of 6 pound density Kaowool blanket. The kiln will be painted with two (2) coats of grey paint using a heat resistant paint.

The sliding doors on each end of the kiln is hung from a trolley which runs on a straight structural steel track. This structural steel track runs in a direction perpendicular to the kiln and is of such a length that the kiln door can be moved completely out of the way in a sideways direction. The trolley is motorized and connected to a pushbutton station so that it is only necessary to push a button to open and close the door. The door itself is constructed of structural steel with an anchored refractory lining the same as the kiln proper. A tight seal is effected between the door and the kiln by a special sealing arrangement around the perimeter of the door. When the kiln is firing, the door is locked into the closed position by spring loaded locking devices.



MOUNTED OFF DRYER WALL APPROX. 3'-0" FROM FLOOR

DIFFERENTIAL PRESSURE SWITCH DIAPHRAGM MUST BE VERTICAL & LEVEL BUBBLE ON CENTER. PROTECT FROM VIBRATION & HEAT USE BRACKETS FOR MOUNTING SHIM IF REQ'D.

830730 B/M

MAY

NO.	REVISION	BY	DATE
1	ADDED #21 & 22, VENT LINES	RC	

BICKLEY FURNACES, INCORPORATED
PHILADELPHIA, PA. 19114

DRYER EQUIPMENT SCHEMATIC

DATE	SCALE	DRAWN BY	CHK. BY
4-23-74	NONE	RC	

APPROVED
PRINT DATE

1C
30729

TOLERANCES
UNLESS OTHERWISE SPECIFIED

MACHINED SHAPES	WELDMENTS & ASSEMBLIES
DECIMALS ± .005" FRACTIONS ± 1/64" FINISHES	UP TO 10 FT. ±1/16" OVER 10 FT. ±1/8"
CERAMIC SHAPES FRACTIONS ± 1/32"	ANGLES ± 1/4°

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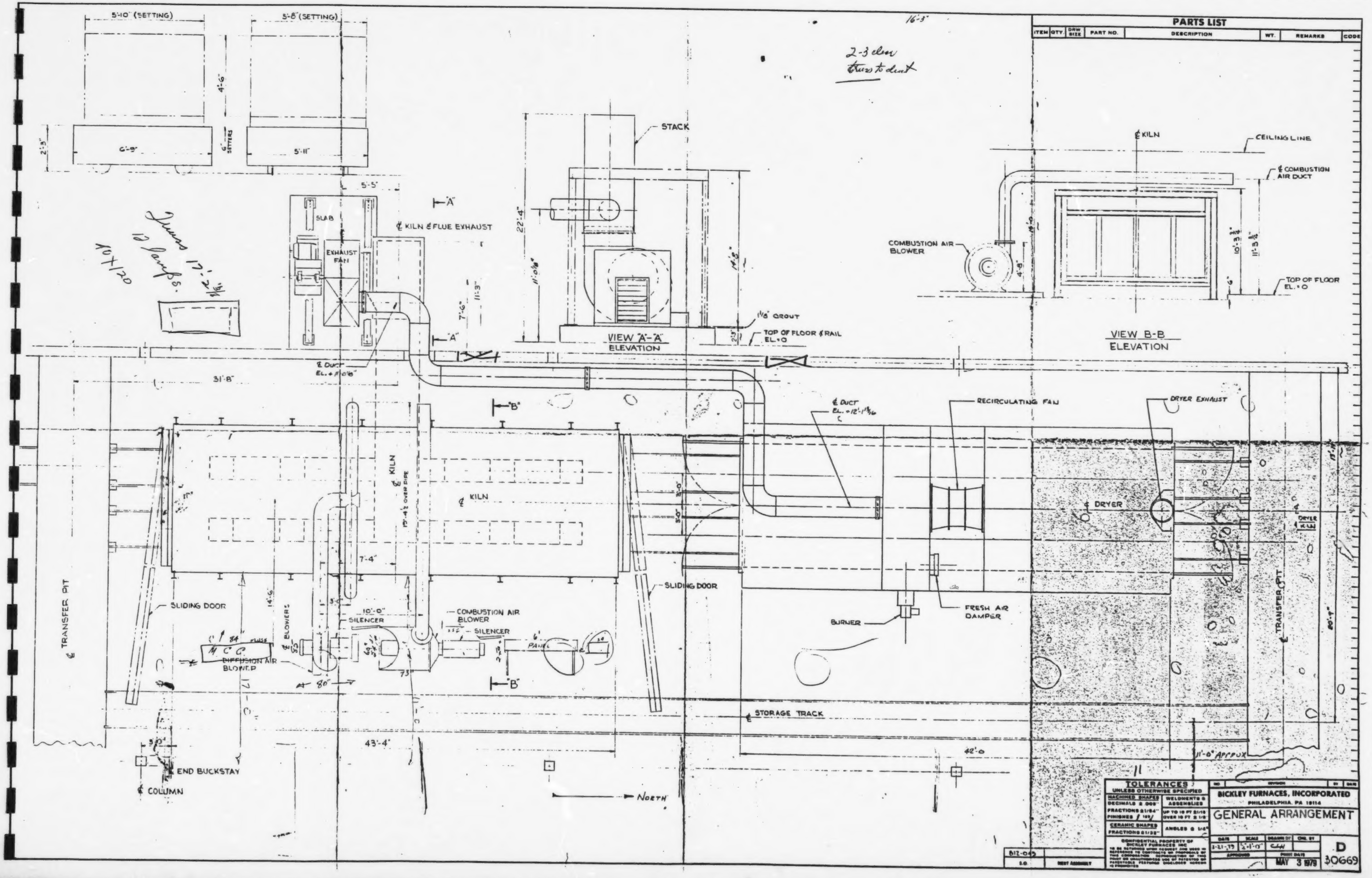
812-045

NO.	NEXT ASSEMBLY

(M)



PARTS LIST

ITEM	QTY.	DRW SIZE	PART NO.	DESCRIPTION	WT.	REMARKS	CODE

TOLERANCES
UNLESS OTHERWISE SPECIFIED

MACHINED SHAPES	WELDMENTS & ASSEMBLIES
DECIMALS ± .005" FRACTIONS ±1/64" FINISHES ∫ 125/	UP TO 10 FT ±1/16" OVER 10 FT ± 1/8"
CERAMIC SHAPES FRACTIONS ±1/32"	ANGLES ± 1/4°

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NO.	REVISION	BY	DATE

BICKLEY FURNACES, INCORPORATED
PHILADELPHIA, PA 19114

GENERAL ARRANGEMENT

DATE	SCALE	DRAWN BY	CHK. BY
3-21-79	¼"=1'-0"	CAH	

APPROVED

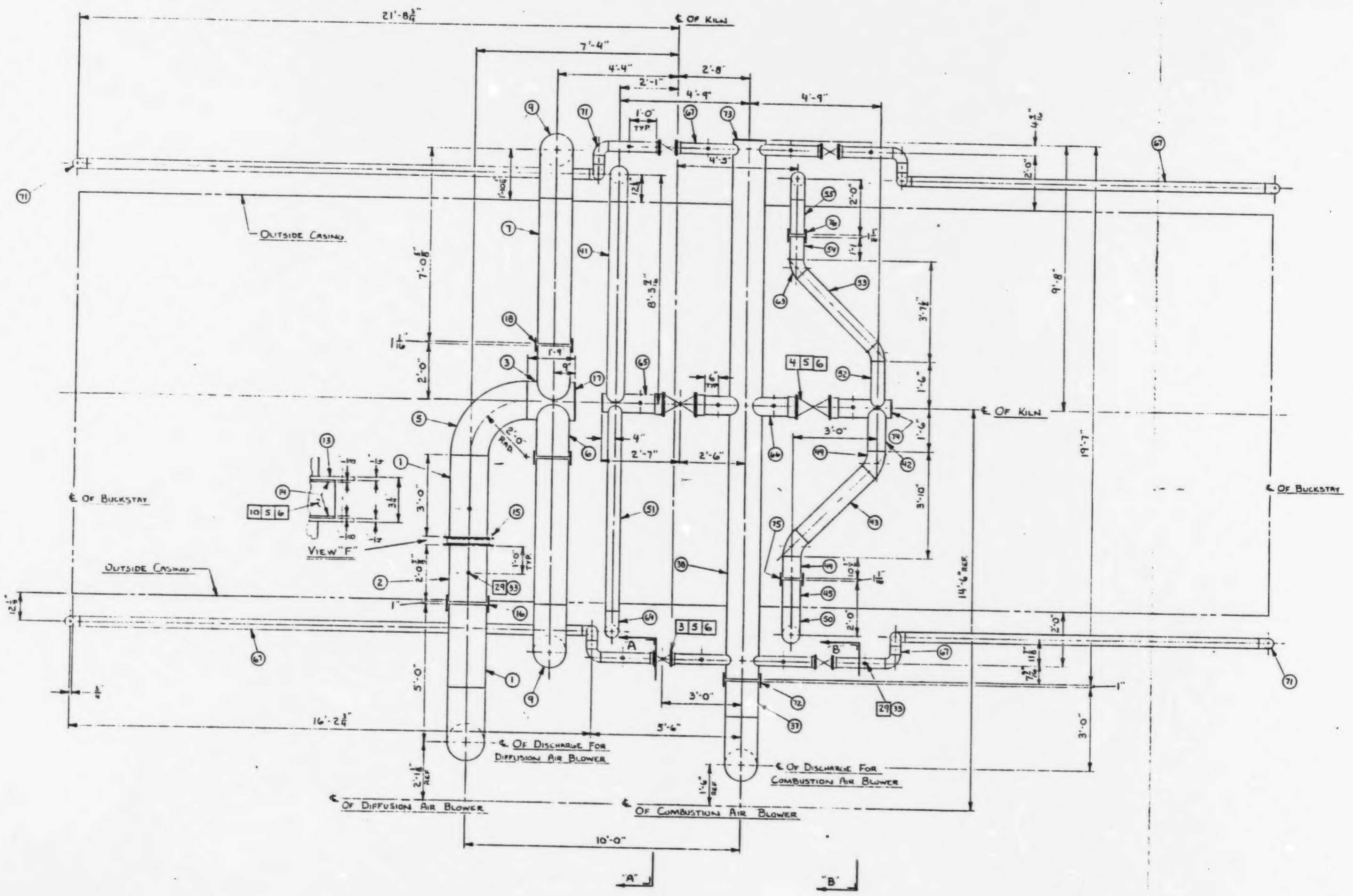
PRINT DATE MAY 3 1979

D
30669

S.O. | NEXT ASSEMBLY

PARTS LIST

ITEM	QTY.	DRW SIZE	PART NO.	DESCRIPTION	WT.	REMARKS	CODE



FOR ITEMS MARKED ☐ SEE COMBUSTION SCHEMATIC B/M B30312

WORK THIS DWG. WITH DWGS D-30822, D 30823, B/M C-30824, D-30825. & D-30826.

812-045	
S.O.	NEXT ASSEMBLY

TOLERANCES
UNLESS OTHERWISE SPECIFIED

MACHINED SHAPES	WELDMENTS & ASSEMBLIES
DECIMALS ± .005"	
FRACTIONS ±1/64"	UP TO 10 FT ±1/16
FINISHES ƒ 125/	OVER 10 FT ± 1/8
CERAMIC SHAPES	
FRACTIONS ±1/32"	ANGLES ± 1/4°

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NO.	REVISION	BY	DATE

BICKLEY FURNACES, INCORPORATED
PHILADELPHIA, PA 19114

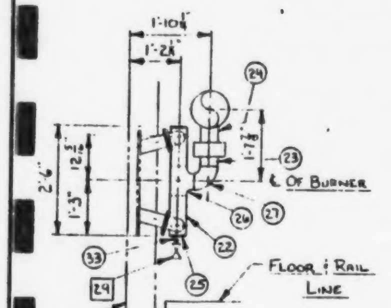
PIPING ARRANGEMENT
DIFFUSION AIR & COMBUSTION AIR
PLAN VIEW

DATE	SCALE	DRAWN BY	CHK. BY
3-30-79	½ =1'-0	JDA	
APPROVED		PRINT DATE	
		APR 20 1979	

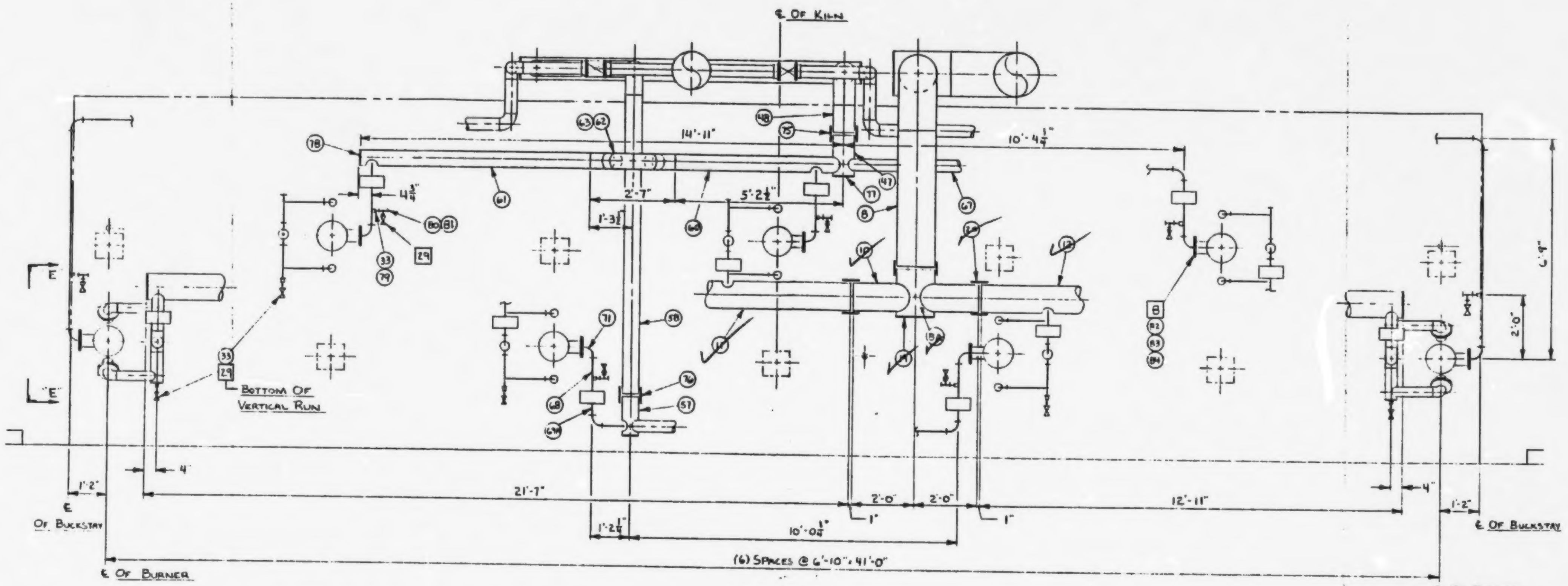
D
30821

PARTS LIST

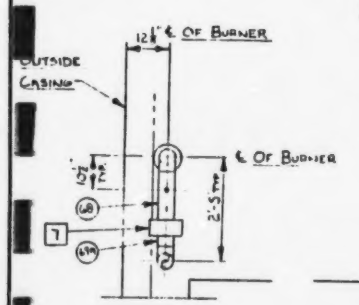
ITEM	QTY	DRW SIZE	PART NO	DESCRIPTION	WT	REMARKS	CODE



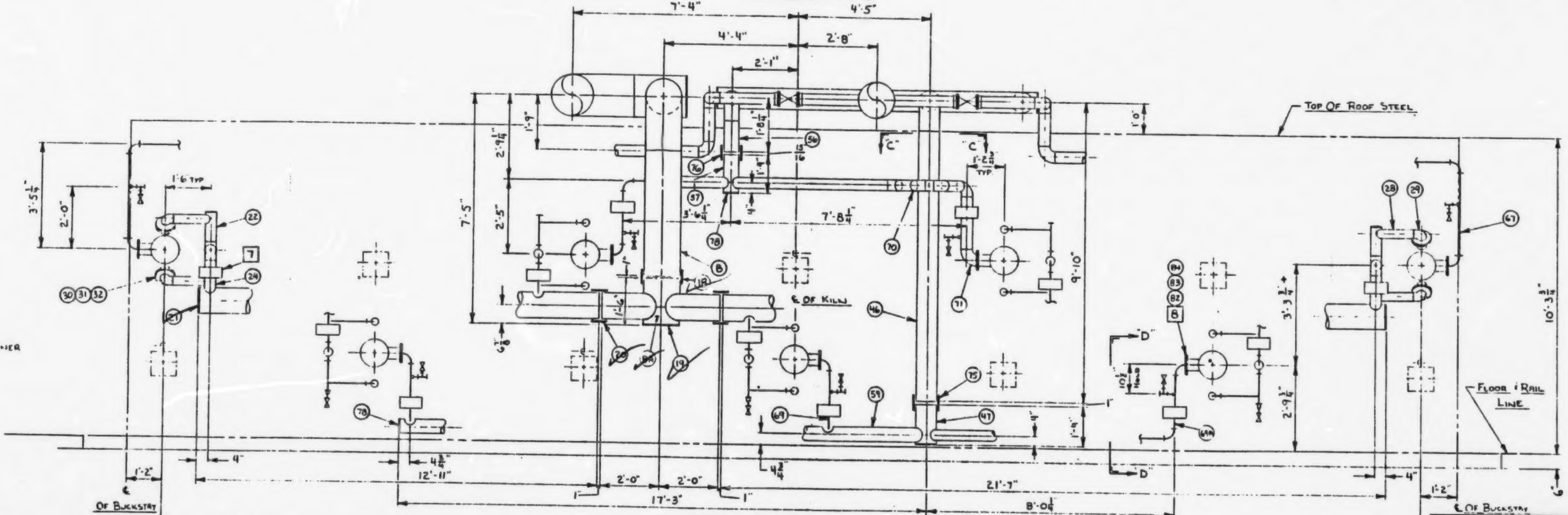
SECTION "E-E"



WEST ELEVATION



SECTION "D-D"



EAST ELEVATION

℄ Of Burner

FOR ITEMS MARKED ☐ SEE COMBUSTION SCHEMATIC B/M B 30312

WORK THIS DWG WITH DWGS. D-30821, D-30823, B/M C-30824, D-30825, & D-30826

812-045	
S.O.	NEXT ASSEMBLY

TOLERANCES
UNLESS OTHERWISE SPECIFIED

MACHINED SHAPES	WELDMENTS & ASSEMBLIES
DECIMALS ± .005 FRACTIONS ± 1/64" FINISHES ƒ 125/	UP TO 10 FT ± 1/16 OVER 10 FT ± 1/8
CERAMIC SHAPES FRACTIONS ± 1/32"	ANGLES ± 1/4°

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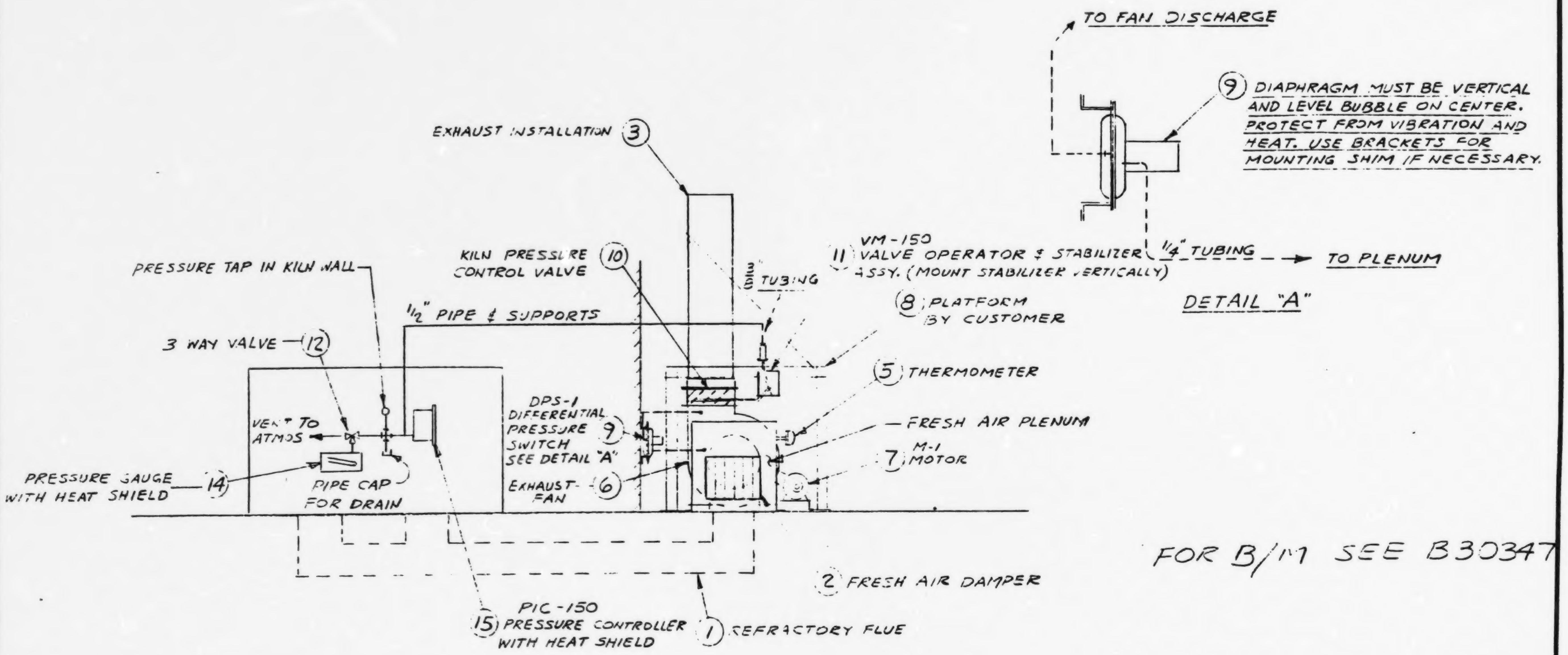
NO	REVISION	BY	DATE

BICKLEY FURNACES, INCORPORATED
PHILADELPHIA, PA 19114

Piping Arrangement
East & West Side

DATE	SCALE	DRAWN BY	CHK. BY
3-30-79	½ = 1-0	JDA	
APPROVED		PRINT DATE	
		APR 20 1979	

D
30822


TO FAN DISCHARGE
9 DIAPHRAGM MUST BE VERTICAL AND LEVEL BUBBLE ON CENTER. PROTECT FROM VIBRATION AND HEAT. USE BRACKETS FOR MOUNTING SHIM IF NECESSARY.
EXHAUST INSTALLATION 3
KILN PRESSURE CONTROL VALVE 10
PRESSURE TAP IN KILN WALL
3/8" TUBING
11 VM-150 VALVE OPERATOR & STABILIZER ASSY. (MOUNT STABILIZER VERTICALLY)
1/4" TUBING
TO PLENUM
DETAIL "A"
1/2" PIPE & SUPPORTS
8 PLATFORM BY CUSTOMER
3 WAY VALVE 12
5 THERMOMETER
VENT TO ATMOS
DPS-1 DIFFERENTIAL PRESSURE SWITCH SEE DETAIL "A" 9
FRESH AIR PLENUM
7 M-1 MOTOR
PRESSURE GAUGE WITH HEAT SHIELD 14
PIPE CAP FOR DRAIN
EXHAUST-FAN 6
FOR B/M SEE B30347
2 FRESH AIR DAMPER
15 PIC-150 PRESSURE CONTROLLER WITH HEAT SHIELD
1 REFRACTORY FLUE

TOLERANCES
UNLESS OTHERWISE SPECIFIED

MACHINED SHAPES	WELDMENTS & ASSEMBLIES
DECIMALS ± .005"	
FRACTIONS ± 1/64"	UP TO 10 FT. ±1/16"
FINISHES ƒ 125√	OVER 10 FT. ±1/8"
CERAMIC SHAPES FRACTIONS ± 1/32"	ANGLES ± 1/4"

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NO.	REVISION	BY	DATE

BICKLEY FURNACES, INCORPORATED
PHILADELPHIA, PA. 19114

EXHAUST SCHEMATIC

DATE	SCALE	DRAWN BY	CHK. BY
1/30/79	~	JPD	
APPROVED	CODE	PRINT DATE	
		MAY 16 1979	

B
30346

S.O. 812-045

13

POOR

QUALITY

ORIGINAL